

DIVISIONAL APPLICATION

UNDER 37 CFR § 1.53(B)

TITLE: NOVEL PURINE INHIBITORS OF FRUCTOSE-1,6-BISPHOSPHATASE

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Utility Application Transmittal Sheet and FY 2001 Fee Transmittal Sheet (2 pgs); Description (100pgs); Claims (21pgs); Abstract (3pgs); Figures 1-11 (10pgs); Preliminary Amendment (49pgs); Information Disclosure Statement (2pgs); PTO-Form 1449 (2pgs); Copies of 40 listed references; Copy of Combined Declaration and Power of Attorney from Patent Application Serial No. 09/036,327 (3pgs); Copy of Revocation Grant of Power of Attorney filed in Patent Application Serial No. 09/036,327 (2pgs); Check in the amount of \$1,030.00; and Return Postcard.

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"EXPRESS MAIL" Mailing Label Number EL675945535US Date of Deposit August 30, 2001 I hereby certify under 37 CFR §1.10 that this correspondence (along with anything referred to as being attached or enclosed) is being deposited with the United States Postal Service as "Express Mail Post Office to Addressee" with sufficient postage on the date indicated above and is addressed to the Commissioner for Patents, Washington, D.C. 20231.



Josh Gibbs

NOVEL PURINE INHIBITORS OF FRUCTOSE-1,6-BISPHOSPHATASE**Field of the Invention**

This invention relates to novel purine compounds that are inhibitors of Fructose-1,6-bisphosphatase at the AMP site. The invention also relates to the preparation and 5 use of these purine analogs in the treatment of diabetes, and other diseases where the inhibition of gluconeogenesis, control of blood glucose levels, reduction in glycogen stores, or reduction in insulin levels is beneficial.

Background and Introduction to the Invention

Diabetes mellitus (or diabetes) is one of the most prevalent diseases in the world 10 today. Diabetes patients have been divided into two classes, namely type I or insulin-dependent diabetes mellitus and type II or non-insulin dependent diabetes mellitus (NIDDM). Non-insulin-dependent diabetes mellitus (NIDDM) accounts for approximately 90% of all diabetics and is estimated to affect 12-14 million adults in the U. S. alone (6.6% of the population). NIDDM is characterized by both fasting 15 hyperglycemia and exaggerated postprandial increases in plasma glucose levels. NIDDM is associated with a variety of long-term complications, including microvascular diseases such as retinopathy, nephropathy and neuropathy, and macrovascular diseases such as coronary heart disease. Numerous studies in animal models demonstrate a causal relationship between long term complications and 20 hyperglycemia. Recent results from the Diabetes Control and Complications Trial (DCCT) and the Stockholm Prospective Study demonstrate this relationship for the first time in man by showing that insulin-dependent diabetics with tighter glycemic control are at substantially lower risk for development and progression of these complications. Tighter control is also expected to benefit NIDDM patients.

25 Current therapies used to treat NIDDM patients entail both controlling lifestyle risk factors and pharmaceutical intervention. First-line therapy for NIDDM is typically

a tightly-controlled regimen of diet and exercise since an overwhelming number of NIDDM patients are overweight or obese (~67%) and since weight loss can improve insulin secretion, insulin sensitivity and lead to normoglycemia. Normalization of blood glucose occurs in less than 30% of these patients due to poor compliance and

5 poor response. Patients with hyperglycemia not controlled by diet alone are subsequently treated with oral hypoglycemics or insulin. Until recently, the sulfonylureas were the only class of oral hypoglycemic agents available for NIDDM. Treatment with sulfonylureas leads to effective blood glucose lowering in only 70% of patients and only 40% after 10 years of therapy. Patients that fail to respond to diet and
10 sulfonylureas are subsequently treated with daily insulin injections to gain adequate glycemic control.

Although the sulfonylureas represent a major therapy for NIDDM patients, four factors limit their overall success. First, as mentioned above, a large segment of the NIDDM population do not respond adequately to sulfonylurea therapy (*i.e.* primary failures) or become resistant (*i.e.* secondary failures). This is particularly true in
15 NIDDM patients with advanced NIDDM since these patients have severely impaired insulin secretion. Second, sulfonylurea therapy is associated with an increased risk of severe hypoglycemic episodes. Third, chronic hyperinsulinemia has been associated with increased cardiovascular disease although this relationship is considered
20 controversial and unproven. Last, sulfonylureas are associated with weight gain, which leads to worsening of peripheral insulin sensitivity and thereby can accelerate the progression of the disease.

Recent results from the U.K. Diabetes prospective study also showed that patients undergoing maximal therapy of a sulfonylurea, metformin, or a combination of
25 the two, were unable to maintain normal fasting glycemia over the six year period of the study. U.K. Prospective Diabetes Study 16. Diabetes, 44:1249-158 (1995). These results further illustrate the great need for alternative therapies. Three therapeutic strategies that could provide additional health benefits to NIDDM patients beyond the

currently available therapies, include drugs that would: (i) prevent the onset of NIDDM; (ii) prevent diabetic complications by blocking detrimental events precipitated by chronic hyperglycemia; or (iii) normalize glucose levels or at least decrease glucose levels below the threshold reported for microvascular and macrovascular diseases.

5 Hyperglycemia in NIDDM is associated with two biochemical abnormalities, namely insulin resistance and impaired insulin secretion. The relative roles of these metabolic abnormalities in the pathogenesis of NIDDM has been the subject of numerous studies over the past several decades. Studies of offspring and siblings of NIDDM patients, mono- and dizygotic twins, and ethnic populations with high

10 incidence of NIDDM (*e.g.* Pima Indians) strongly support the inheritable nature of the disease.

Despite the presence of insulin resistance and impaired insulin secretion, fasting blood glucose (FBG) levels remain normal in pre-diabetic patients due to a state of compensatory hyperinsulinemia. Eventually, however, insulin secretion is inadequate

15 and fasting hyperglycemia ensues. With time insulin levels decline. Progression of the disease is characterized by increasing FBG levels and declining insulin levels.

Numerous clinical studies have attempted to define the primary defect that accounts for the progressive increase in FBG. Results from these studies indicate that excessive hepatic glucose output (HGO) is the primary reason for the elevation in FBG

20 with a significant correlation found for HGO and FBG once FBG exceeds 140 mg/dL. Kolterman, et al., J. Clin. Invest. 68:957, (1981); DeFronzo Diabetes 37:667 (1988).

HGO comprises glucose derived from breakdown of hepatic glycogen (glycogenolysis) and glucose synthesized from 3-carbon precursors (gluconeogenesis). A number of radioisotope studies and several studies using ¹³C-NMR spectroscopy

25 have shown that gluconeogenesis contributes between 50-100% of the glucose produced by the liver in the postabsorptive state and that gluconeogenesis flux is excessive (2- to 3-fold) in NIDDM patients. Magnusson, et al. J. Clin. Invest. 90:1323-1327 (1992);

Rothman, et al., Science 254: 573-76 (1991); Consoli, et al. Diabetes 38:550-557 (1989).

Gluconeogenesis from pyruvate is a highly regulated biosynthetic pathway requiring eleven enzymes (Figure 1). Seven enzymes catalyze reversible reactions and 5 are common to both gluconeogenesis and glycolysis. Four enzymes catalyze reactions unique to gluconeogenesis, namely pyruvate carboxylase, phosphoenolpyruvate carboxykinase, fructose-1,6-bisphosphatase and glucose-6-phosphatase. Overall flux through the pathway is controlled by the specific activities of these enzymes, the enzymes that catalyzed the corresponding steps in the glycolytic direction, and by 10 substrate availability. Dietary factors (glucose, fat) and hormones (insulin, glucagon, glucocorticoids, epinephrine) coordinatively regulate enzyme activities in the gluconeogenesis and glycolysis pathways through gene expression and post-translational mechanisms.

Of the four enzymes specific to gluconeogenesis, fructose-1,6-bisphosphatase 15 (hereinafter "FBPase") is the most suitable target for a gluconeogenesis inhibitor based on efficacy and safety considerations. Studies indicate that nature uses the FBPase/PFK cycle as a major control point (metabolic switch) responsible for determining whether metabolic flux proceeds in the direction of glycolysis or gluconeogenesis. Claus, et al., Mechanisms of Insulin Action, Belfrage, P. editor, pp.305-321, Elsevier Science 1992; 20 Regen, et al. J. Theor. Biol., 111:635-658 (1984); Pilkis, et al. Annu. Rev. Biochem., 57:755-783 (1988). FBPase is inhibited by fructose-2,6-bisphosphate in the cell. Fructose-2,6-bisphosphate binds to the substrate site of the enzyme. AMP binds to an allosteric site on the enzyme.

Synthetic inhibitors of FBPase have also been reported. McNeil reported that 25 fructose-2,6-bisphosphate analogs inhibit FBPase by binding to the substrate site. J. Med. Chem., 106:7851 (1984); U.S. Patent No. 4,968,790 (1984). These compounds, however, were relatively weak and did not inhibit glucose production in hepatocytes presumably due to poor cell penetration.

Gruber reported that some nucleosides can lower blood glucose in the whole animal through inhibition of FBPase. These compounds exert their activity by first undergoing phosphorylation to the corresponding monophosphate. EP 0 427 799 B1.

Gruber et al. U.S. Patent No. 5,658,889 described the use of inhibitors of the AMP site of FBPase to treat diabetes.

European patent application EP 0 632 048 A1 discloses certain ethyl phosphonates of purine derivatives for use as antiviral and antineoplastic agents. These structures differ from the claimed compounds because they have no substitution on the C-8 of the purine. There is no suggestion that these compounds are inhibitors of FBPase.

Brief Description of the Drawings

FIG. 1 is a scheme depicting the eleven enzymes of the gluconeogenesis pathway.

FIG. 2 shows the dose-dependent inhibition of hPFBPase AMP and compounds 2.7, 2.13, and 2.5.

FIG. 3 shows the displacement of ^3H -AMP from hPFBPase by ZMP and compound 2.2.

FIG. 4A depicts the reduction of glucose production from dihydroxyacetone in rat hepatocytes treated with compound 2.7.

FIG. 4B depicts the increase in the amount of fructose-1,6-bisphosphate in rat hepatocytes exposed to dihydroxyacetone and treated with compound 2.7.

FIG. 5 depicts a dose-dependent inhibition of glucose production in rat hepatocytes exposed to lactate and pyruvate by compounds 2.7 and 2.1.

FIG. 6 shows the effect of various doses of compound 16.4 on blood glucose levels in 18 hour fasted, normal rats.

FIG. 7 is a bar graph depicting the reduction in blood glucose levels in 18 hour fasted normal rats treated with compound 2.7 given at a dose of 20 mg/kg i.p.

FIG. 8 is a bar graph depicting the increased accumulation of fructose-1,6-bisphosphate in the liver of 18-hour fasted rats treated with compound 2.7.

FIG. 9A is a bar graph depicting a reduction in blood glucose levels in 24 hour fasted Zucker Diabetic Fatty rats treated with compound 2.7.

5 FIG. 9B is a bar graph depicting the percentage change in blood glucose levels in 24 hour fasted Zucker Diabetic Fatty rats treated with compound 2.7.

FIG. 10 depicts the inhibition of gluconeogenesis from ^{14}C -bicarbonate in 24 hour fasted Diabetic Fatty rats treated with compound 2.7.

10 FIG. 11A depicts the dose-dependent inhibition of glucose production in rat hepatocytes by compound 16.4, a prodrug of compound 2.7.

FIG. 11B shows the intracellular generation of compound 2.7 in rat hepatocytes treated with compound 16.4, a prodrug, to inhibit glucose production in rat hepatocytes.

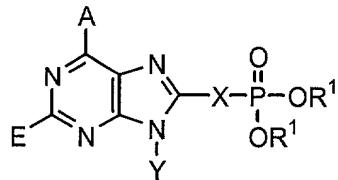
Summary of the Invention

The present invention is directed towards novel purine compounds which bind 15 the AMP site and are potent FBPase inhibitors. In another aspect, the present invention is directed to the preparation of these novel purine compounds and to the *in vitro* and *in vivo* FBPase inhibitory activity of these compounds. Another aspect of the present invention is directed to the clinical use of the novel FBPase inhibitors as a method of treatment or prevention of diseases responsive to inhibition of gluconeogenesis and in 20 diseases responsive to lowered blood glucose levels.

Gruber et al. U.S. patent application Serial Number 08/355,836 (allowed) described the use of inhibitors of the AMP site of FBPase to treat diabetes.

The compounds are also useful in treating or preventing excess glycogen storage 25 diseases and insulin dependent diseases such as cardiovascular diseases including atherosclerosis.

The invention comprises the novel purine analogs as specified below in formula 1. Also included in the scope of the present invention are prodrugs of the compounds of formula 1.



Formula 1

Since these compounds may have asymmetric centers, the present invention is directed not only to racemic mixtures of these compounds, but also to individual 5 stereoisomers. The present invention also includes pharmaceutically acceptable and/or useful salts of the compounds of formula 1, including acid addition salts and basic salts. The present inventions also encompass prodrugs of compounds of formula 1.

Definitions

In accordance with the present invention and as used herein, the following terms 10 are defined with the following meanings, unless explicitly stated otherwise.

The term “aryl” refers to aromatic groups which have at least one ring having a conjugated pi electron system and includes carbocyclic aryl, heterocyclic aryl and biaryl groups, all of which may be optionally substituted.

Carbocyclic aryl groups are groups wherein the ring atoms on the aromatic ring 15 are carbon atoms. Carbocyclic aryl groups include monocyclic carbocyclic aryl groups and polycyclic or fused compounds such as optionally substituted naphthyl groups.

Heterocyclic aryl groups are groups having from 1 to 4 heteroatoms as ring atoms in the aromatic ring and the remainder of the ring atoms being carbon atoms.

Suitable heteroatoms include oxygen, sulfur, and nitrogen. Suitable heteroaryl groups 20 include furanyl, thienyl, pyridyl, pyrrolyl, N-lower alkyl pyrrolyl, pyridyl-N-oxide, pyrimidyl, pyrazinyl, imidazolyl, and the like, all optionally substituted.

The term “biaryl” represents aryl groups containing more than one aromatic ring including both fused ring systems and aryl groups substituted with other aryl groups.

The term "alicyclic" means compounds which combine the properties of aliphatic and cyclic compounds and include but are not limited to aromatic, cycloalkyl and bridged cycloalkyl compounds. The cyclic compound includes heterocycles. Cyclohexenylethyl, cyclohexanylethyl, and norbornyl are suitable alicyclic groups.

5 Such groups may be optionally substituted.

The term "optionally substituted" or "substituted" includes groups substituted by one to four substituents, independently selected from lower alkyl, lower aryl, lower aralkyl, lower alicyclic, hydroxy, lower alkoxy, lower aryloxy, perhaloalkoxy, aralkoxy, heteroaryl, heteroaryloxy, heteroarylalkyl, heteroaralkoxy, azido, amino, guanidino, halogen, lower alkylthio, oxa, ketone, carboxy esters, carboxyl, carboxamido, nitro, acyloxy, alkylamino, aminoalkyl, alkylaminoaryl, alkylaryl, alkylaminoalkyl, alkoxyaryl, arylamino, aralkylamino, phosphonate, sulfonate, carboxamidoalkylaryl, carboxamidoaryl, hydroxyalkyl, haloalkyl, alkylaminoalkylcarboxy, aminocarboxamidoalkyl, cyano, lower alkoxyalkyl, and lower perhaloalkyl.

The term "aralkyl" refers to an alkyl group substituted with an aryl group. Suitable aralkyl groups include benzyl, picolyl, and the like, and may be optionally substituted.

The term "lower" referred to herein in connection with organic radicals or compounds respectively defines such as with up to and including 10, preferably up to and including 6, and advantageously one to four carbon atoms. Such groups may be straight chain, branched, or cyclic.

The terms "arylamino" (a), and "aralkylamino" (b), respectively, refer to the group -NRR' wherein respectively, (a) R is aryl and R' is hydrogen, alkyl, aralkyl or aryl, and (b) R is aralkyl and R' is hydrogen or aralkyl, aryl, alkyl.

The term "acyl" refers to -C(O)R where R is alkyl and aryl.

The term "carboxy esters" refers to -C(O)OR where R is alkyl, aryl, aralkyl, and alicyclic, all optionally substituted.

The term "oxa" refers to =O in an alkyl group.

The term "alkylamino" refers to -NRR' where R and R' are independently selected from hydrogen or alkyl.

The term "carbonylamine" or "carbonylamino" refers to -CONR₂ where each R 5 is independently hydrogen or alkyl.

The term "halogen" or "halo" refers to -F, -Cl, -Br and -I.

The term "oxyalkylamino" refers to -O-alk-NR-, where "alk" is an alkylene group and R is H or alkyl.

The term "alkylsulfonate" refers to the group -alk-S(O)₂-O- where "alk" is an 10 alkylene group.

The term "alkylaminoalkylcarboxy" refers to the group -alk-NR-alk-C(O)-O- where "alk" is an alkylene group, and R is a H or lower alkyl.

The term "alkylaminocarbonyl" refers to the group -alk-NR-C(O)- where "alk" is an alkylene group, and R is a H or lower alkyl.

The term "oxyalkyl" refers to the group -O-alk- where "alk" is an alkylene 15 group.

The term "alkylcarboxyalkyl" refers to the group -alk-C(O)-O-alkyl where each alk is independently an alkylene group.

The term "alkyl" refers to saturated aliphatic groups including straight-chain, 20 branched chain and cyclic groups. Alkyl groups may be optionally substituted.

The term "bidentate" refers to an alkyl group that is attached by its terminal ends to the same atom to form a cyclic group. For example, propylene imine contains a bidentate propylene group.

The term "cyclic alkyl" refers to alkyl groups that are cyclic.

The term "heterocyclic" and "heterocyclic alkyl" refer to cyclic alkyl groups 25 containing at least one heteroatom. Suitable heteroatoms include oxygen, sulfur, and nitrogen. Heterocyclic groups may be attached through a heteroatom or through a carbon atom in the ring.

The term "alkenyl" refers to unsaturated groups which contain at least one carbon-carbon double bond and includes straight-chain, branched-chain and cyclic groups. Alkene groups may be optionally substituted.

5 The term "alkynyl" refers to unsaturated groups which contain at least one carbon-carbon triple bond and includes straight-chain, branched-chain and cyclic groups. Alkyne groups may be optionally substituted.

The term "alkylene" refers to a divalent straight chain, branched chain or cyclic saturated aliphatic radical.

10 The term "acyloxy" refers to the ester group -O-C(O)R, where R is H, alkyl, alkenyl, alkynyl, aryl, aralkyl, or alicyclic.

The term "alkylaryl" refers to the group -alk-aryl- where "alk" is an alkylene group. "Lower alkylaryl" refers to such groups where alkylene is lower alkyl.

The term "alkylamino" refers to the group -alk-NR- wherein "alk" is an alkylene group.

15 The term "alkyl(carboxyl)" refers to carboxyl substituted off the alkyl chain. Similarly, "alkyl(hydroxy)", "alkyl(phosphonate)", and "alkyl(sulfonate)" refers to substituents off the alkyl chain.

The term "alkylaminoalkyl" refers to the group -alk-NR-alk- wherein each "alk" is an independently selected alkylene, and R is H or lower alkyl. "Lower alkylaminoalkyl" refers to groups where each alkylene group is lower alkyl.

The term "alkylaminoaryl" refers to the group -alk-NR-aryl- wherein "alk" is an alkylene group. In "lower alkylaminoaryl", the alkylene group is lower alkyl.

The term "alkyloxyaryl" refers to an alkylene group substituted with an aryloxy group. In "lower alkyloxyaryl", the alkylene group is lower alkyl.

25 The term "alkylacylamino" refers to the group -alk-N-(COR)- wherein alk is alkylene and R is lower alkyl. In "lower alkylacylamino", the alkylene group is lower alkyl.

The term "alkoxyalkylaryl" refers to the group -alk-O-alk-aryl- wherein each "alk" is independently an alkylene group. "Lower alkoxyalkylaryl" refers to such groups where the alkylene group is lower alkyl.

5 The term "alkylacylaminoalkyl" refers to the group -alk-N-(COR)-alk- where each alk is an independently selected alkylene group. In "lower alkylacylaminoalkyl" the alkylene groups are lower alkyl.

The term "alkoxy" refers to the group -alk-O- wherein alk is an alkylene group.

10 The term "alkoxyalkyl" refers to the group -alk-O-alk- wherein each alk is an independently selected alkylene group. In "lower alkoxyalkyl", each alkylene is lower alkyl.

The term "alkylthio" refers to the group -alk-S- wherein alk is alkylene group.

The term "alkylthioalkyl" refers to the group -alk-S-alk- wherein each alk is an independently selected alkylene group. In "lower alkylthioalkyl" each alkylene is lower alkylene.

15 The term "aralkylamino" refers to an amine substituted with an aralkyl group.

The term "alkylcarboxamido" refers to the group -alk-C(O)N(R)- wherein alk is an alkylene group and R is H or lower alkyl.

20 The term "alkylcarboxamidoalkyl" refers to the group -alk-C(O)N(R)-alk- wherein each alk is an independently selected alkylene group and R is lower alkyl. In "lower alkylcarboxamidoalkyl" each alkylene is lower alkyl.

The term "alkylcarboxamidoalkylaryl" refers to the group -alk₁-C(O)-NH-alk₂Ar- wherein alk₁ and alk₂ are independently selected alkylene groups and alk₂ is substituted with an aryl group, Ar. In "lower alkylcarboxamidoalkylaryl", each alkylene is lower alkyl.

25 The term "heteroalicyclic" refers to an alicyclic group having 1 to 4 heteroatoms selected from nitrogen, sulfur, phosphorus and oxygen.

The term "aminocarboxamidoalkyl" refers to the group -NH-C(O)-N(R)-R wherein each R is an independently selected alkyl group. "Lower aminocaboxamidoalkyl" refers to such groups wherein each R is lower alkyl.

5 The term "heteroarylalkyl" refers to an alkyl group substituted with a heteroaryl group.

The term "perhalo" refers to groups wherein every C-H bond has been replaced with a C-halo bond on an aliphatic or aryl group. Suitable perhaloalkyl groups include -CF₃ and -CFCl₂.

10 The term "guanidine" refers to both -NR-C(NR)-NR₂ as well as -N=C(NR₂)₂ where each R group is independently selected from the group of -H, alkyl, alkenyl, alkynyl, aryl, and alicyclic, all optionally substituted.

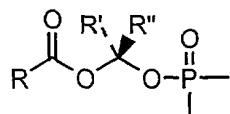
The term "amidine" refers to -C(NR)-NR₂ where each R group is independently selected from the group of -H, alkyl, alkenyl, alkynyl, aryl, and alicyclic, all optionally substituted.

15 The term "pharmaceutically acceptable salt" includes salts of compounds of formula 1 and its prodrugs derived from the combination of a compound of this invention and an organic or inorganic acid or base.

20 The term "prodrug" as used herein refers to any compound that when administered to a biological system generates the "drug" substance either as a result of spontaneous chemical reaction(s) or by enzyme catalyzed or metabolic reaction(s). Reference is made to various prodrugs such as acyl esters, carbonates, and carbamates, included herein. The groups illustrated are exemplary, not exhaustive, and one skilled in the art could prepare other known varieties of prodrugs. Such prodrugs of the compounds of formula 1, fall within the scope of the present invention.

25 The term "prodrug ester" as employed herein includes, but is not limited to, the following groups and combinations of these groups:

[1] Acyloxyalkyl esters which are well described in the literature (Farquhar et al., J. Pharm. Sci. 72, 324-325 (1983)) and are represented by formula A



Formula A

wherein R, R', and R'' are independently H, alkyl, aryl, alkylaryl, and alicyclic; (see WO 90/08155; WO 90/10636).

[2] Other acyloxyalkyl esters are possible in which an alicyclic ring is formed such as shown in formula B. These esters have been shown to generate phosphorus-containing nucleotides inside cells through a postulated sequence of reactions beginning with deesterification and followed by a series of elimination reactions (e.g. Freed et al., Biochem. Pharm. 38: 3193-3198 (1989)).



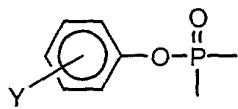
Formula B

wherein R is -H, alkyl, aryl, alkylaryl, alkoxy, aryloxy, alkylthio, arylthio, alkylamino, arylamino, cycloalkyl, or alicyclic.

[3] Another class of these double esters known as alkyloxycarbonyloxymethyl esters, as shown in formula A, where R is alkoxy, aryloxy, alkylthio, arylthio, alkylamino, and arylamino; R', and R'' are independently H, alkyl, aryl, alkylaryl, and alicyclic, have been studied in the area of β -lactam antibiotics (Tatsuo Nishimura et al. *J. Antibiotics*, 1987, 40(1), 81-90; for a review see Ferres, H.,

Drugs of Today, 1983, 19, 499.). More recently Cathy, M. S., et al. (Abstract from AAPS Western Regional Meeting, April, 1997) showed that these alkyloxycarbonyloxymethyl ester prodrugs on (9-[(R)-2-phosphonomethoxy]propyl]adenine (PMPA) are bioavailable up to 30% in dogs.

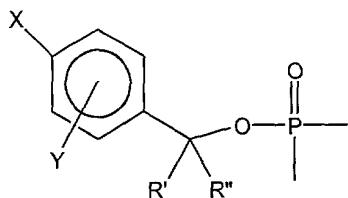
5 [4] Aryl esters have also been used as phosphonate prodrugs (e.g. Erion, DeLambert et al., *J. Med. Chem.* 37: 498, 1994; Serafinowska et al., *J. Med. Chem.* 38: 1372, 1995). Phenyl as well as mono and poly-substituted phenyl phosphonate ester prodrugs have generated the parent phosphonic acid in studies conducted in animals and in man (Formula C). Another approach has been described where Y is a carboxylic 10 ester ortho to the phosphate. Khamnei and Torrence, *J. Med. Chem.*; 39:4109-4115 (1996).



Formula C

wherein 15 Y is H, alkyl, aryl, alkylaryl, alkoxy, acetoxy, halogen, amino, alkoxycarbonyl, hydroxy, cyano, alkylamino, and alicyclic.

[5] Benzyl esters have also been reported to generate the parent phosphonic acid. In some cases, using substituents at the para-position can accelerate the hydrolysis. Benzyl analogs with 4-acyloxy or 4-alkyloxy group [Formula D, X = H, OR or O(CO)R or O(CO)OR] can generate the 4-hydroxy compound more readily 20 through the action of enzymes, e.g. oxidases, esterases, etc. Examples of this class of prodrugs are described by Mitchell et al., *J. Chem. Soc. Perkin Trans. I* 2345 (1992); Brook, et al. WO 91/19721.



Formula D

wherein X and Y are independently H, alkyl, aryl, alkylaryl, alkoxy, acetoxy, hydroxy, cyano, nitro, perhaloalkyl, halo, or alkyloxycarbonyl; and

5 R' and R'' are independently H, alkyl, aryl, alkylaryl, halogen, and alicyclic.

[6] Thio-containing phosphonate phosphonate ester prodrugs have been described that are useful in the delivery of FBPase inhibitors to hepatocytes. These phosphonate ester prodrugs contain a protected thioethyl moiety as shown in formula E.

10 One or more of the oxygens of the phosphonate can be esterified. Since the mechanism that results in de-esterification requires the generation of a free thiolate, a variety of thiol protecting groups are possible. For example, the disulfide is reduced by a reductase-mediated process (Puech et al., Antiviral Res., 22: 155-174 (1993)). Thioesters will also generate free thiolates after esterase-mediated hydrolysis.

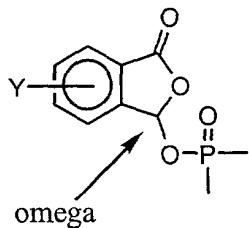
15 Benzaria, et al., J. Med. Chem., 39:4958 (1996). Cyclic analogs are also possible and were shown to liberate phosphonate in isolated rat hepatocytes. The cyclic disulfide shown below has not been previously described and is novel.



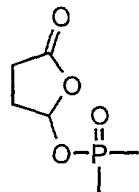
Formula E

wherein Z is alkylcarbonyl, alkoxycarbonyl, arylcarbonyl, aryloxycarbonyl, or alkylthio.

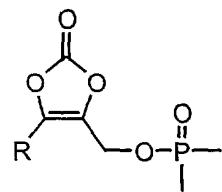
Other examples of suitable prodrugs include proester classes exemplified by Biller and Magnin (U.S. Patent No. 5,157,027); Serafinowska et al. (*J. Med. Chem.* 38, 5 1372 (1995)); Starrett et al. (*J. Med. Chem.* 37, 1857 (1994)); Martin et al. (*J. Pharm. Sci.* 76, 180 (1987); Alexander et al., *Collect. Czech. Chem. Commun.* 59, 1853 (1994)); and EPO patent application 0 632 048 A1. Some of the structural classes described are optionally substituted, including fused lactones attached at the omega position and optionally substituted 2-oxo-1,3-dioxolenes attached through a methylene 10 to the phosphorus oxygen such as:



3-phthalidyl



2-oxotetrahydrofuran-5-yl

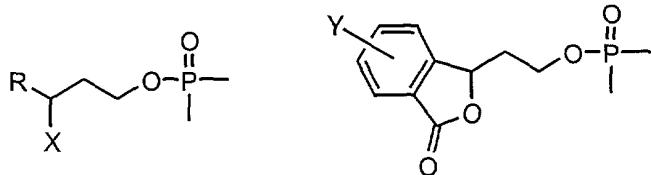


2-oxo-4,5-dihydro-1,3-dioxolanemethyl

wherein R is -H, alkyl, cycloalkyl, or alicyclic; and

wherein Y is -H, alkyl, aryl, alkylaryl, cyano, alkoxy, acetoxy, halogen, amino, alkylamino, alicyclic, and alkoxycarbonyl.

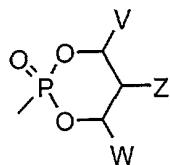
[7] Propyl phosphonate ester prodrugs can also be used to deliver FBPase 15 inhibitors into hepatocytes. These phosphonate ester prodrugs may contain a hydroxyl and hydroxyl group derivatives at the 3-position of the propyl group as shown in formula F. The R and X groups can form a cyclic ring system as shown in formula F. One or more of the oxygens of the phosphonate can be esterified.



Formula F

wherein R is alkyl, aryl, heteroaryl;
 X is hydrogen, alkylcarbonyloxy, alkyloxycarbonyloxy; and
 Y is alkyl, aryl, heteroaryl, alkoxy, alkylamino, alkylthio, halogen,
 5 hydrogen, hydroxy, acetoxy, amino.

[8] The cyclic propyl phosphonate esters as in Formula G are shown to activate to phosphonic acids. The activation of prodrug can be mechanistically explained by *in vivo* oxidation and elimination steps. These prodrugs inhibit glucose production in isolated rat hepatocytes and are also shown to deliver FBPase inhibitors to 10 the liver following oral administration.



Formula G

wherein

V and W are independently selected from the group consisting of hydrogen, 15 aryl, substituted aryl, heteroaryl, substituted heteroaryl, 1-alkenyl, 1-alkynyl, and -R⁹; or together V and Z are connected to form a cyclic group containing 3-5 atoms, optionally 1 heteroatom, substituted with hydroxy, acyloxy, alkoxyacetoxy, or aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus; or
 20 together V and W are connected to form a cyclic group containing 3 carbon atoms substituted with hydroxy, acyloxy, alkoxyacetoxy, alkylthiocarboxy,

hydroxymethyl, and aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus;

Z is selected from the group consisting of -CH₂OH, -CH₂OCOR³,
-CH₂OC(O)SR³, -CH₂OCO₂R³, -SR³, -S(O)R³, -CH₂N₃, -CH₂NR², -CH₂Ar,
5 -CH(Ar)OH, -CH(CH=CR²R²)OH, -CH(C=CR²)OH, and -R²;

with the provisos that:

- a) V, Z, W are not all -H; and
- b) when Z is -R², then at least one of V and W is not -H or -R⁹;

R² is selected from the group consisting of R³ and -H;
10 R³ is selected from the group consisting of alkyl, aryl, alicyclic, and aralkyl; and
R⁹ is selected from the group consisting of alkyl, aralkyl, and alicyclic.

[9] Phosphoramidate derivatives have been explored as potential phosphonate prodrugs (e.g. McGuigan et al., *Antiviral Res.* 1990, 14: 345; 1991, 15 : 255. Serafinowska et al., *J. Med. Chem.*, 1995, 38, 1372). Most phosphoramidates are 15 unstable under aqueous acidic conditions and are hydrolyzed to the corresponding phosphonic acids. Cyclic phosphoramidates have also been studied as phosphonate prodrugs because of their potential for greater stability compared to non cyclic phosphoramidates (e.g. Starrett et al., *J. Med. Chem.*, 1994, 37: 1857).

Other prodrugs are possible based on literature reports such as substituted ethyls 20 for example, bis(trichloroethyl)esters as disclosed by McGuigan, et al. Bioorg Med. Chem. Lett., 3:1207-1210 (1993), and the phenyl and benzyl combined nucleotide esters reported by Meier, C. et al. Bioorg. Med. Chem. Lett., 7:99-104 (1997).

X group nomenclature as used herein in formula 1 describes the group attached 25 to the phosphonate and ends with the group attached to the 2-position of the benzimidazole ring. For example, when X is alkylamino, the following structure is intended:

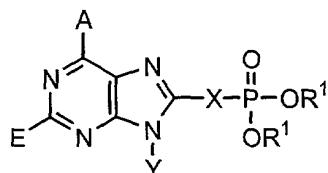


Y group nomenclature likewise ends with the group attached to the ring.

DETAILED DESCRIPTION OF THE INVENTION

Novel Purine Compounds

Preferred compounds of the present invention are inhibitors of the AMP site of FBPase of the following formula (1):



wherein

A is selected from the group consisting of -NR⁸₂, NHSO₂R³, -OR⁵, -SR⁵, halogen, lower alkyl, -CON(R⁴)₂, guanidine, amidine, -H, and perhaloalkyl;

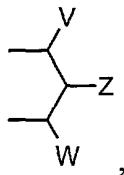
E is selected from the group consisting of -H, halogen, lower alkylthio, lower perhaloalkyl, lower alkyl, lower alkenyl, lower alkynyl, lower alkoxy, -CN, and -NR⁷₂;

X is selected from the group consisting of alkylamino, alkyl, alkenyl, alkynyl, alkyl(carboxyl), alkyl(hydroxy), alkyl(phosphonate), alkyl(sulfonate), aryl, alkylaminoalkyl, alkoxyalkyl, alkylthioalkyl, alkylthio, alicyclic, 1,1-dihaloalkyl, carbonylalkyl, aminocarbonylamino, alkylaminocarbonyl, alkylcarbonylamino, aralkyl, and alkylaryl, all optionally substituted; or together with Y forms a cyclic group including cyclic alkyl, heterocyclic, and aryl;

Y is selected from the group consisting of -H, alkyl, alkenyl, alkynyl, aryl, alicyclic, aralkyl, aryloxyalkyl, alkoxyalkyl, -C(O)R³, -S(O)₂R³, -C(O)-OR³, -CONHR³, -NR²₂, and -OR³, all except H are optionally substituted; or together with X forms a cyclic group including aryl, cyclic alkyl, and heterocyclic;

R¹ is independently selected from the group consisting of -H, alkyl, aryl, alicyclic where the cyclic moiety contains a carbonate or thiocarbonate, -C(R²)₂-aryl, alkylaryl, -C(R²)₂OC(O)NR²₂, -NR²-C(O)-R³, -C(R²)₂-OC(O)R³, C(R²)₂-O-C(O)OR³,

-C(R²)₂OC(O)SR³, alkyl-S-C(O)R³, alkyl-S-S-alkylhydroxy, and alkyl-S-S-S-alkylhydroxy, or together R¹ and R¹ are -alkyl-S-S-alkyl to form a cyclic group, or together R¹ and R¹ are



5 wherein

V and W are independently selected from the group consisting of hydrogen, aryl, substituted aryl, heteroaryl, substituted heteroaryl, 1-alkenyl, 1-alkynyl, and -R⁹; or

together V and Z are connected to form a cyclic group containing 3-5 atoms, optionally 1 heteroatom, substituted with hydroxy, acyloxy, alkoxy carboxy, or

10 aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus; or

together V and W are connected to form a cyclic group containing 3 carbon atoms substituted with hydroxy, acyloxy, alkoxy carboxy, alkylthiocarboxy, hydroxymethyl, and aryloxycarboxy attached to a carbon atom that is three atoms from

15 an oxygen attached to the phosphorus;

Z is selected from the group consisting of -CH₂OH, -CH₂OCOR³, -CH₂OC(O)SR³, -CH₂OCO₂R³, -SR³, -S(O)R³, -CH₂N₃, -CH₂NR²₂, -CH₂Ar, -CH(Ar)OH, -CH(CH=CR²R²)OH, -CH(C≡CR²)OH, and -R²;

with the provisos that:

20 a) V, Z, W are not all -H; and

b) when Z is -R², then at least one of V and W is not -H or -R⁹;

R² is selected from the group consisting of R³ and -H;

R³ is selected from the group consisting of alkyl, aryl, alicyclic, and aralkyl;

R⁴ is independently selected from the group consisting of -H, lower alkyl, lower alicyclic, lower aralkyl, and lower aryl;

R⁵ is selected from the group consisting of lower alkyl, lower aryl, lower aralkyl, and lower alicyclic;

5 R⁶ is independently selected from the group consisting of -H, and lower alkyl;

R⁷ is independently selected from the group consisting of -H, lower alkyl, lower alicyclic, lower aralkyl, lower aryl, and -C(O)R¹⁰;

R⁸ is independently selected from the group consisting of -H, lower alkyl, lower aralkyl, lower aryl, lower alicyclic, -C(O)R¹⁰, or together they form a bidentate alkyl;

10 R⁹ is selected from the group consisting of alkyl, aralkyl, and alicyclic;

R¹⁰ is selected from the group consisting of -H, lower alkyl, -NH₂, lower aryl, and lower perhaloalkyl;

R¹¹ is selected from the group consisting of alkyl, aryl, -OH, -NH₂ and -OR³;
and

15 pharmaceutically acceptable prodrugs and salts thereof.

Preferred Compounds of Formula 1

Suitable alkyl groups include groups having from 1 to about 20 carbon atoms.

Suitable aryl groups include groups having from 1 to about 20 carbon atoms. Suitable aralkyl groups include groups having from 2 to about 21 carbon atoms. Suitable

20 acyloxy groups include groups having from 1 to about 20 carbon atoms. Suitable alkylene groups include groups having from 1 to about 20 carbon atoms. Suitable alicyclic groups include groups having 3 to about 20 carbon atoms. Suitable heteroaryl groups include groups having from 1 to about 20 carbon atoms and from 1 to 5 heteroatoms, preferably independently selected from nitrogen, oxygen, phosphorous, and sulfur. Suitable heteroalicyclic groups include groups having from 2 to about twenty carbon atoms and from 1 to 5 heteroatoms, preferably independently selected from nitrogen, oxygen, phosphorous, and sulfur.

Preferred A groups include -NR⁸₂, lower alkyl, lower perhaloalkyl, lower alkoxy, and halogen. Particularly preferred are -NR⁸₂, and halogen. Especially preferred is -NR⁸₂. Most preferred is -NH₂.

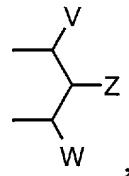
Preferred E groups include -H, halogen, lower perhaloalkyl, -CN, lower alkyl, 5 lower alkoxy, and lower alkylthio. Particularly preferred E groups include -H, -SMe, -Et, and -Cl. Especially preferred is -H and -SCH₃.

Preferred X groups include alkylamino, alkyl, alkynyl, alkoxyalkyl, alkylthio, aryl, 1,1-dihaloalkyl, carbonylalkyl, heteroaryl, alkylcarbonylamino, and alkylaminocarbonyl. Particularly preferred is alkyl substituted with 1 to 3 substituents 10 selected from halogen, phosphonate, -CO₂H, -SO₃H, and -OH. Particularly preferred are alkylaminocarbonyl, alkoxyalkyl, and heteroaryl. Preferred alkoxyalkyl groups include methoxymethyl. Preferred heteroaryl groups include furanyl, optionally substituted.

Preferred Y groups include aralkyl, alicyclic, alkyl, and aryl, all optionally substituted. Particularly preferred is lower alkyl. Particularly preferred Y groups 15 include (2-naphthyl)methyl, cyclohexylethyl, phenylethyl, nonyl, cyclohexylpropyl, ethyl, cyclopropylmethyl, cyclobutylmethylphenyl, (2-methyl)propyl, neopentyl, cyclopropyl, cyclopentyl, (1-imidozolyl)propyl, 2-ethoxybenzyl, 1-hydroxy-2,2-dimethylpropyl, 1-chloro-2,2-dimethylpropyl, 2,2-dimethylbutyl, 2-(spiro-3',3'- 20 dimethylcyclohex-4-enyl)propyl, and 1-methylneopentyl. Especially preferred is neopentyl and isobutyl.

Preferred R⁴ and R⁷ groups are -H, and lower alkyl. Particularly preferred are -H, and methyl.

Preferred R¹ groups include -H, alkyl, aryl, alicyclic where the cyclic moiety 25 contains a carbonate or thiocarbonate, -C(R²)₂-aryl, alkylaryl, -C(R²)₂OC(O)NR²₂, -NR²-C(O)-R³, -C(R²)₂-OC(O)R³, C(R²)₂-O-C(O)OR³, -C(R²)₂OC(O)SR³, alkyl-S-C(O)R³, alkyl-S-S-alkylhydroxy, and alkyl-S-S-S-alkylhydroxy, or together R¹ and R¹ are -alkyl-S-S-alkyl to form a cyclic group, or together R¹ and R¹ are



wherein

V and W are independently selected from the group consisting of hydrogen, aryl, substituted aryl, heteroaryl, substituted heteroaryl, 1-alkenyl, 1-alkynyl, and -R⁹; or

5 together V and Z are connected to form a cyclic group containing 3-5 atoms, optionally 1 heteroatom, substituted with hydroxy, acyloxy, alkoxy carboxy, or aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus; or

10 together V and W are connected to form a cyclic group containing 3 carbon atoms substituted with hydroxy, acyloxy, alkoxy carboxy, alkylthiocarboxy, hydroxymethyl, and aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus;

Z is selected from the group consisting of -CH₂OH, -CH₂OCOR³, -CH₂OC(O)SR³, -CH₂OCO₂R³, -SR³, -S(O)R³, -CH₂N₃, -CH₂NR²₂, -CH₂Ar, 15 -CH(Ar)OH, -CH(CH=CR²R²)OH, -CH(C≡CR²)OH, and -R²;

with the provisos that:

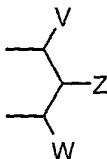
- a) V, Z, W are not all -H; and
- b) when Z is -R², then at least one of V and W is not -H or -R⁹;

R² is selected from the group consisting of R³ and -H;

20 R³ is selected from the group consisting of alkyl, aryl, alicyclic, and aralkyl; and R⁹ is selected from the group consisting of alkyl, aralkyl, and alicyclic.

Preferred R¹ groups include -H, alkylaryl, aryl, -C(R²)₂-aryl, and -C(R²)₂-OC(O)R³. Preferred such R¹ groups include optionally substituted phenyl, optionally substituted benzyl, -H, -C(R²)₂OC(O)OR³, and -C(R²)₂OC(O)R³. Preferably, said alkyl groups are greater than 4 carbon atoms. Another preferred aspect is where at least one R¹ is aryl or -C(R²)₂-aryl. Also particularly preferred are compounds where R¹ is

alicyclic where the cyclic moiety contains carbonate or thiocarbonate. Another preferred aspect is when at least one R¹ is -C(R²)₂-OC(O)R³, -C(R²)₂-OC(O)OR³ or -C(R²)₂-OC(O)SR³. Also particularly preferred is when R¹ and R¹ together are optionally substituted, including fused, lactone attached at the omega position or are 5 optionally substituted 2-oxo-1,3-dioxolenes attached through a methylene to the phosphorus oxygen. Also preferred is when at least one R¹ is -alkyl-S-S-alkylhydroxyl, -alkyl-S-C(O)R³, and -alkyl-S-S-alkylhydroxy, or together R¹ and R¹ are -alkyl-S-S-alkyl- to form a cyclic group. Also preferred is where R¹ and R¹ together are



10 to form a cyclic group,
wherein

V and W are independently selected from the group consisting of hydrogen, aryl, substituted aryl, heteroaryl, substituted heteroaryl, 1-alkenyl, 1-alkynyl, and -R⁹; or

15 together V and Z are connected to form a cyclic group containing 3-5 atoms,

optionally 1 heteroatom, substituted with hydroxy, acyloxy, alkoxy carboxy, or aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus; or

20 together V and W are connected to form a cyclic group containing 3 carbon atoms substituted with hydroxy, acyloxy, alkoxy carboxy, alkylthiocarboxy,

hydroxymethyl, and aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus;

25 Z is selected from the group consisting of -CH₂OH, -CH₂OCOR³, -CH₂OC(O)SR³, -CH₂OCO₂R³, -SR³, -S(O)R³, -CH₂N₃, -CH₂NR²₂, -CH₂Ar, -CH(Ar)OH, -CH(CH=CR²R²)OH, -CH(C≡CR²)OH, and -R²;

with the provisos that:

a) V, Z, W are not all -H; and

b) when Z is -R², then at least one of V and W is not -H or -R⁹;
 R² is selected from the group consisting of R³ and -H;
 R³ is selected from the group consisting of alkyl, aryl, alicyclic, and aralkyl; and
 R⁹ is selected from the group consisting of alkyl, aralkyl, and alicyclic.

5

Particularly preferred are such groups wherein V and W both form a 6-membered carbocyclic ring substituted with 0-4 groups, selected from the group consisting of hydroxy, acyloxy, alkoxycarbonyl, and alkoxy; and Z is R². Also particularly preferred are such groups wherein V and W are hydrogen; and Z is selected from the group consisting of hydroxyalkyl, acyloxyalkyl, alkyloxyalkyl, and alkoxycarboxyalkyl. Also particularly preferred are such groups wherein V and W are independently selected from the group consisting of hydrogen, optionally substituted aryl, and optionally substituted heteroaryl, with the proviso that at least one of V and W is optionally substituted aryl or optionally substituted heteroaryl.

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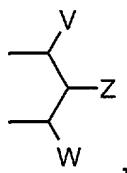
In one preferred aspect, R¹ is not lower alkyl of 1-4 carbon atoms.

In another preferred aspect, A is -NR₂⁸ or halogen, E is -H, halogen, -CN, lower alkyl, lower perhaloalkyl, lower alkoxy, or lower alkylthio, X is alkylamino, alkyl, alkoxyalkyl, alkynyl, 1,1-dihaloalkyl, carbonylakyl, alkyl(OH), alkyl(sulfonate), alkylcarbonylamino, alkylaminocarbonyl, alkylthio, aryl, or heteroaryl, and R⁴ and R⁷

15

20

is -H or lower alkyl. Particularly preferred are such compounds where Y is aralkyl, aryl, alicyclic, or alkyl. Especially preferred are such compounds where R¹ and R¹ together are



wherein

25

V and W are independently selected from the group consisting of hydrogen, aryl, substituted aryl, heteroaryl, substituted heteroaryl, 1-alkenyl, 1-alkynyl, and -R⁹; or

together V and Z are connected to form a cyclic group containing 3-5 atoms, optionally 1 heteroatom, substituted with hydroxy, acyloxy, alkoxy, or aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus; or

5 together V and W are connected to form a cyclic group containing 3 carbon atoms substituted with hydroxy, acyloxy, alkoxy, alkylthiocarboxy, hydroxymethyl, and aryloxycarboxy attached to a carbon atom that is three atoms from an oxygen attached to the phosphorus;

Z is selected from the group consisting of -CH₂OH, -CH₂OCOR³,
10 -CH₂OC(O)SR³, -CH₂OCO₂R³, -SR³, -S(O)R³, -CH₂N₃, -CH₂NR²₂, -CH₂Ar,
-CH(Ar)OH, -CH(CH=CR²R²)OH, -CH(C≡CR²)OH, and -R²;

with the provisos that:

- a) V, Z, W are not all -H; and
- b) when Z is -R², then at least one of V and W is not -H or -R⁹;

15 R² is selected from the group consisting of R³ and -H;

R³ is selected from the group consisting of alkyl, aryl, alicyclic, and aralkyl; and

R⁹ is selected from the group consisting of alkyl, aralkyl, and alicyclic.

In another preferred aspect, A is -NR⁸₂, E is -H, Cl-, or methylthio, and X is optionally substituted furanyl, or alkoxyalkyl. Particularly preferred are such compounds where A is -NH₂, X is 2,5-furanyl, or methoxymethyl, and Y is lower alkyl. Most preferred are such compounds where E is H, X is 2,5-furanyl, and Y is neopentyl; those where E is -SCH₃, X is 2,5-furanyl, and Y is isobutyl; and those where E is -H, X is 2,5-furanyl, and Y is 1-(3-chloro-2,2-dimethyl)-propyl. Especially preferred are such compounds where R¹ is -CH₂O-C(O)-C(CH₃)₃.

25 In the following examples of preferred compounds, the following prodrugs are preferred:

Acyloxyalkyl esters;

Alkoxycarbonyloxyalkyl esters;

Aryl esters;

Benzyl and substituted benzyl esters;

Disulfide containing esters;

Substituted (1,3-dioxolen-2-one)methyl esters;

5 Substituted 3-phthalidyl esters;

Cyclic-[2'-hydroxymethyl]-1,3-propanyl diesters and hydroxy protected forms;

Lactone type esters; and all mixed esters resulted from possible combinations of above esters.

Bis-pivaloyloxymethyl esters;

10 Bis-isobutyryloxymethyl esters;

Cyclic-[2'-hydroxymethyl]-1,3-propanyl diester;

Cyclic-[2'-acetoxyxymethyl]-1,3-propanyl diester;

Cyclic-[2'-methylloxycarbonyloxymethyl]-1,3-propanyl diester;

Bis-benzoylthiomethyl esters;

15 Bis-benzoylthioethyl esters;

Bis-benzoyloxymethyl esters;

Bis-*p*-fluorobenzoyloxymethyl esters;

Bis-6-chloronicotinoyloxymethyl esters;

Bis-5-bromonicotinoyloxymethyl esters;

20 Bis-thiophenecarbonyloxymethyl esters;

Bis-2-furoyloxymethyl esters;

Bis-3-furoyloxymethyl esters;

Diphenyl esters;

Bis-(4-methoxyphenyl) esters;

25 Bis-(2-methoxyphenyl) esters;

Bis-(2-ethoxyphenyl) esters;

Mono-(2-ethoxyphenyl) esters;

Bis-(4-acetamidophenyl) esters;

Bis-(4-aceyloxyphenyl) esters;
Bis-(4-hydroxyphenyl) esters;
Bis-(2-acetoxyphenyl) esters;
Bis-(3-acetoxyphenyl) esters;

5 Bis-(4-morpholinophenyl) esters;
Bis-[4-(1-triazolophenyl) esters;
Bis-(3-N,N-dimethylaminophenyl) esters;
Bis-(2-tetrahydronaphthyl) esters;
Bis-(3-chloro-4-methoxy)benzyl esters;

10 Bis-(3-bromo-4-methoxy)benzyl esters;
Bis-(3-cyano-4-methoxy)benzyl esters;
Bis-(3-chloro-4-acetoxy)benzyl esters;
Bis-(3-bromo-4-acetoxy)benzyl esters;
Bis-(3-cyano-4-acetoxy)benzyl esters;

15 Bis-(4-chloro)benzyl esters;
Bis-(4-acetoxy)benzyl esters;
Bis-(3,5-dimethoxy-4-acetoxy)benzyl esters;
Bis-(3-methyl-4-acetoxy)benzyl esters;
Bis-(benzyl)esters;

20 Bis-(3-methoxy-4-acetoxy)benzyl esters;
Bis-(3-chloro-4-acetoxy)benzyl esters;
cyclic-(2,2-dimethylpropyl)phosphonoamidate;
cyclic-(2-hydroxymethylpropyl) ester;
Bis-(6'-hydroxy-3',4'-disulfide)hexyl esters;

25 Bis-(6'-acetoxy-3',4'-disulfide)hexyl esters;
(3',4'-Dithia)cyclononane esters;
Bis-(5-methyl-1,3-dioxolen-2-one-4-yl)methyl esters;
Bis-(5-ethyl-1,3-dioxolen-2-one-4-yl)methyl esters;

Bis-(5-tert-butyl-1,3-dioxolen-2-one-4-yl)methyl esters;
Bis-3-(5,6,7-trimethoxy)phthalidyl esters;
Bis-(cyclohexyloxycarbonyloxymethyl) esters;
Bis-(isopropyloxycarbonyloxymethyl) esters;

5 Bis-(ethyloxycarbonyloxymethyl) esters;
Bis-(methyloxycarbonyloxymethyl) esters;
Bis-(isopropylthiocarbonyloxymethyl) esters;
Bis-(phenyloxycarbonyloxymethyl) esters;
Bis-(benzyloxycarbonyloxymethyl) esters;

10 Bis-(phenylthiocarbonyloxymethyl) esters;
Bis-(*p*-methoxyphenyloxycarbonyloxymethyl) esters;
Bis-(*m*-methoxyphenyloxycarbonyloxymethyl) esters;
Bis-(*o*-methoxyphenyloxycarbonyloxymethyl) esters;
Bis-(*o*-methylphenyloxycarbonyloxymethyl) esters;

15 Bis-(*p*-chlorophenyloxycarbonyloxymethyl) esters;
Bis-(1,4-biphenyloxycarbonyloxymethyl) esters;
Bis-[(2-phthalimidoethyl)oxygenyloxymethyl]esters;
Bis-(*N*-Phenyl, *N*-methylcarbamoyloxymethyl) esters;
Bis-(2-trichloroethyl) esters;

20 Bis-(2-bromoethyl) esters;
Bis-(2-iodoethyl) esters;
Bis-(2-azidoethyl) esters;
Bis-(2-acetoxyethyl) esters;
Bis-(2-aminoethyl) esters;

25 Bis-(2-N,N-diaminoethyl) esters;
Bis-(2-aminoethyl) esters;
Bis-(methoxycarbonylmethyl) esters;
Bis-(2-aminoethyl) esters;

Bis-[*N,N*-di(2-hydroxyethyl)]amidomethylesters;
Bis-(2-aminoethyl) esters;
Bis-(2-methyl-5-thiazolomethyl) esters;
Bis-(bis-2-hydroxyethylamidomethyl) esters.

5 Most preferred are the following:

Bis-pivaloyloxymethyl esters;

Bis-isobutyryloxymethyl esters;

cyclic-(2-hydroxymethylpropyl) ester;

cyclic-(2-acetoxymethylpropyl) ester;

10 cyclic-(2-methyloxycarbonyloxymethylpropyl) ester;

cyclic-(2-cyclohexylcarbonyloxymethylpropyl)ester;

cyclic-(2-aminomethylpropyl)ester;

cyclic-(2-azidomethylpropyl)ester;

Bis-benzoylthiomethyl esters;

15 Bis-benzoylthioethylesters;

Bis-benzoyloxymethyl esters;

Bis-*p*-fluorobenzoyloxymethyl esters;

Bis-6-chloronicotinoyloxymethyl esters;

Bis-5-bromonicotinoyloxymethyl esters;

20 Bis-thiophenecarbonyloxymethyl esters;

Bis-2-furoyloxymethyl esters;

Bis-3-furoyloxymethyl esters;

Diphenyl esters;

Bis-(2-methyl)phenyl esters;

25 Bis-(2-methoxy)phenyl esters;

Bis-(2-ethoxy)phenyl esters;

Bis-(4-methoxy)phenyl esters;

Bis-(3-bromo-4-methoxy)benzyl esters;

Bis-(4-acetoxy)benzyl esters;

Bis-(3,5-dimethoxy-4-acetoxy)benzyl esters;

Bis-(3-methyl-4-acetoxy)benzyl esters;

Bis-(3-methoxy-4-acetoxy)benzyl esters;

5 Bis-(3-chloro-4-acetoxy)benzyl esters;

Bis-(cyclohexyloxycarbonyloxymethyl) esters;

Bis-(isopropyloxycarbonyloxymethyl) esters;

Bis-(ethyloxycarbonyloxymethyl) esters;

Bis-(methyloxycarbonyloxymethyl) esters;

10 Bis-(isopropylthiocarbonyloxymethyl) esters;

Bis-(phenyloxycarbonyloxymethyl) esters;

Bis-(benzyloxycarbonyloxymethyl) esters;

Bis-(phenylthiocarbonyloxymethyl) esters;

Bis-(*p*-methoxyphenyloxycarbonyloxymethyl) esters;

15 Bis-(*m*-methoxyphenyloxycarbonyloxymethyl) esters;

Bis-(*o*-methoxyphenyloxycarbonyloxymethyl) esters;

Bis-(*o*-methylphenyloxycarbonyloxymethyl) esters;

Bis-(*p*-chlorophenyloxycarbonyloxymethyl) esters;

Bis-(1,4-biphenyloxycarbonyloxymethyl) esters;

20 Bis-[(2-phthalimidoethyl)oxygenyloxymethyl]esters;

Bis-(6'-hydroxy-3',4'-disulfide)hexyl esters; and

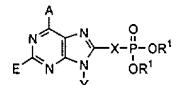
(3',4'-Disulfide)cyclononane esters.

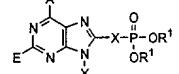
Bis-(2-bromoethyl) esters;

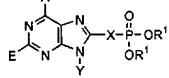
Bis-(2-aminoethyl) esters;

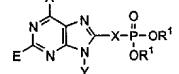
25 Bis-(2-*N,N*-diaminoethyl) esters;

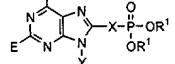
Examples of preferred compounds include, but are not limited to those described in Table 1 including salts and prodrugs thereof:

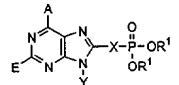
| Table Compound No. | Synthetic Example No. | | |  | |
|-----------------------|--------------------------|---------|-----|--|-------------|
| | | A | E | Y | X |
| 1 | 2.7 | NH2 | H | neopentyl | 2,5-furanyl |
| 2 | | H | H | neopentyl | 2,5-furanyl |
| 3 | | Me | H | neopentyl | 2,5-furanyl |
| 4 | | Et | H | neopentyl | 2,5-furanyl |
| 5 | | Pr | H | neopentyl | 2,5-furanyl |
| 6 | | I | H | neopentyl | 2,5-furanyl |
| 7 | | Br | H | neopentyl | 2,5-furanyl |
| 8 | | Cl | H | neopentyl | 2,5-furanyl |
| 9 | | F | H | neopentyl | 2,5-furanyl |
| 10 | | OMe | H | neopentyl | 2,5-furanyl |
| 11 | | OEt | H | neopentyl | 2,5-furanyl |
| 12 | | OPr | H | neopentyl | 2,5-furanyl |
| 13 | | SMe | H | neopentyl | 2,5-furanyl |
| 14 | | SEt | H | neopentyl | 2,5-furanyl |
| 15 | | SPr | H | neopentyl | 2,5-furanyl |
| 16 | | SBn | H | neopentyl | 2,5-furanyl |
| 17 | | OBn | H | neopentyl | 2,5-furanyl |
| 18 | | NHMe | H | neopentyl | 2,5-furanyl |
| 19 | | NHET | H | neopentyl | 2,5-furanyl |
| 20 | | NH-cPr | H | neopentyl | 2,5-furanyl |
| 21 | | NHOH | H | neopentyl | 2,5-furanyl |
| 22 | | NHNH2 | H | neopentyl | 2,5-furanyl |
| 23 | | NHCHO | H | neopentyl | 2,5-furanyl |
| 24 | | NHAc | H | neopentyl | 2,5-furanyl |
| 25 | | NHCOCF3 | H | neopentyl | 2,5-furanyl |
| 26 | | NHSO2Me | H | neopentyl | 2,5-furanyl |
| 27 | | CONH2 | H | neopentyl | 2,5-furanyl |
| 28 | | ONH2 | H | neopentyl | 2,5-furanyl |
| 29 | 22.2 | NH2 | SMe | neopentyl | 2,5-furanyl |

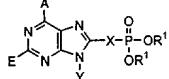
| Table Compound No. | Synthetic Example No. | | |  | |
|-----------------------|--------------------------|----------------------|-----|--|-------------|
| 30 | | H | SMe | neopentyl | 2,5-furanyl |
| 31 | | Me | SMe | neopentyl | 2,5-furanyl |
| 32 | | Et | SMe | neopentyl | 2,5-furanyl |
| 33 | | Pr | SMe | neopentyl | 2,5-furanyl |
| 34 | | I | SMe | neopentyl | 2,5-furanyl |
| 35 | | Br | SMe | neopentyl | 2,5-furanyl |
| 36 | | Cl | SMe | neopentyl | 2,5-furanyl |
| 37 | | F | SMe | neopentyl | 2,5-furanyl |
| 38 | | OMe | SMe | neopentyl | 2,5-furanyl |
| 39 | | OEt | SMe | neopentyl | 2,5-furanyl |
| 40 | | OPr | SMe | neopentyl | 2,5-furanyl |
| 41 | | SMe | SMe | neopentyl | 2,5-furanyl |
| 42 | | SEt | SMe | neopentyl | 2,5-furanyl |
| 43 | | SPr | SMe | neopentyl | 2,5-furanyl |
| 44 | | SBn | SMe | neopentyl | 2,5-furanyl |
| 45 | | OBn | SMe | neopentyl | 2,5-furanyl |
| 46 | | NHMe | SMe | neopentyl | 2,5-furanyl |
| 47 | | NHEt | SMe | neopentyl | 2,5-furanyl |
| 48 | | NH-cPr | SMe | neopentyl | 2,5-furanyl |
| 49 | | NHOH | SMe | neopentyl | 2,5-furanyl |
| 50 | | NHNH ₂ | SMe | neopentyl | 2,5-furanyl |
| 51 | | NHCHO | SMe | neopentyl | 2,5-furanyl |
| 52 | | NHAc | SMe | neopentyl | 2,5-furanyl |
| 53 | | NHCOCF ₃ | SMe | neopentyl | 2,5-furanyl |
| 54 | | NHSO ₂ Me | SMe | neopentyl | 2,5-furanyl |
| 55 | | CONH ₂ | SMe | neopentyl | 2,5-furanyl |
| 56 | | ONH ₂ | SMe | neopentyl | 2,5-furanyl |
| 57 | | NH ₂ | H | isobutyl | 2,5-furanyl |
| 58 | 2.6 | NH ₂ | H | isopropyl | 2,5-furanyl |
| 59 | 2.5 | NH ₂ | H | ethyl | 2,5-furanyl |

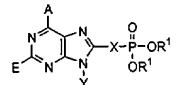
| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|---|--|-------------|
| 60 | | NH2 | H | methyl | 2,5-furanyl |
| 61 | 2.9 | NH2 | H | cyclopropyl | 2,5-furanyl |
| 62 | | NH2 | H | cyclobutyl | 2,5-furanyl |
| 63 | 2.10 | NH2 | H | cyclopentyl | 2,5-furanyl |
| 64 | | NH2 | H | cyclohexyl | 2,5-furanyl |
| 65 | | NH2 | H | cycloheptanyl | 2,5-furanyl |
| 66 | | NH2 | H | cyclopropylmethyl | 2,5-furanyl |
| 67 | | NH2 | H | cyclobutylmethyl | 2,5-furanyl |
| 68 | | NH2 | H | cyclopentylmethyl | 2,5-furanyl |
| 69 | | NH2 | H | 2-cyclopropylethyl | 2,5-furanyl |
| 70 | | NH2 | H | 2-cyclobutylethyl | 2,5-furanyl |
| 71 | | NH2 | H | 2-cyclopentylethyl | 2,5-furanyl |
| 72 | 2.2 | NH2 | H | 2-cyclohexylethyl | 2,5-furanyl |
| 73 | 2.1 | NH2 | H | 2-phenylethyl | 2,5-furanyl |
| 74 | | NH2 | H | benzyl | 2,5-furanyl |
| 75 | | NH2 | H | phenyl | 2,5-furanyl |
| 76 | | NH2 | H | D-ribosyl | 2,5-furanyl |
| 77 | | NH2 | H | H | 2,5-furanyl |
| 78 | | NH2 | H | 1-naphthylmethyl | 2,5-furanyl |
| 79 | 2.3 | NH2 | H | 2-naphthylmethyl | 2,5-furanyl |
| 80 | | NH2 | H | 3-cyclopropylpropyl | 2,5-furanyl |
| 81 | | NH2 | H | 3-cyclobutylpropyl | 2,5-furanyl |
| 82 | | NH2 | H | 3-cyclopentylpropyl | 2,5-furanyl |
| 83 | | NH2 | H | 3-cyclohexylpropyl | 2,5-furanyl |
| 84 | 2.4 | NH2 | H | 2,2-diphenylethyl | 2,5-furanyl |
| 85 | 2.8 | NH2 | H | adamentylmethyl | 2,5-furanyl |
| 86 | 2.11 | NH2 | H | 2-ethoxybenzyl | 2,5-furanyl |

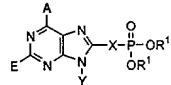
| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|---|--|-------------|
| 87 | 2.13 | NH2 | H | 2,2-dimethyl-3-hydroxy-1-propyl | 2,5-furanyl |
| 88 | 2.12 | NH2 | H | 2,2-dimethyl-3-dimethylamino-1-propyl | 2,5-furanyl |
| 89 | 2.14 | NH2 | H | 2,2-dimethyl-3-chloro-1-propyl | 2,5-furanyl |
| 90 | 2.15 | NH2 | H | 3,3-dimethyl-1-butyl | 2,5-furanyl |
| 91 | 2.17 | NH2 | H | 1,2,2-trimethyl-1-propyl | 2,5-furanyl |
| 92 | 2.16 | NH2 | H | 1,5,5-trimethyl-3-ene-1-cyclohexylmethyl | 2,5-furanyl |
| 93 | | NH2 | H | 4-pyrimidylmethyl | 2,5-furanyl |
| 94 | | NH2 | H | 2-(4-pyrimidyl)ethyl | 2,5-furanyl |
| 95 | | NH2 | H | 5-pyrimidylmethyl | 2,5-furanyl |
| 96 | | NH2 | H | 2-(5-pyrimidyl)ethyl | 2,5-furanyl |
| 97 | | NH2 | H | 2-pyrimidylmethyl | 2,5-furanyl |
| 98 | | NH2 | H | 2-(2-pyrimidyl)ethyl | 2,5-furanyl |
| 99 | | NH2 | H | 2-pyridylmethyl | 2,5-furanyl |
| 100 | | NH2 | H | 2-(2-pyridyl)ethyl | 2,5-furanyl |
| 101 | | NH2 | H | 3-pyridylmethyl | 2,5-furanyl |
| 102 | | NH2 | H | 2-(3-pyridyl)ethyl | 2,5-furanyl |
| 103 | | NH2 | H | 4-pyridylmethyl | 2,5-furanyl |
| 104 | | NH2 | H | 2-(4-pyridyl)ethyl | 2,5-furanyl |
| 105 | | NH2 | H | 2-carbamoyleethyl | 2,5-furanyl |

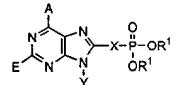
| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|---|--|----------------|
| 106 | | NH2 | H | 1-(2-carbamoyl)propyl | 2,5-furanyl |
| 107 | | NH2 | H | neopentyl | CONHCH2 |
| 108 | | NH2 | H | neopentyl | CONHCH2CH2 |
| 109 | | NH2 | H | neopentyl | CH2CH2CH2 |
| 110 | | NH2 | H | neopentyl | CH2CH2CF2 |
| 111 | 5.5 | NH2 | H | neopentyl | CH2OCH2 |
| 112 | | NH2 | H | neopentyl | CH2OCF2 |
| 113 | | NH2 | H | neopentyl | CF2CF2CF2 |
| 114 | | NH2 | H | neopentyl | acetylene |
| 115 | | NH2 | H | neopentyl | SCH2 |
| 116 | | NH2 | H | neopentyl | SCH2CH2 |
| 117 | | NH2 | H | neopentyl | CH2SCH2 |
| 118 | | NH2 | H | neopentyl | NHCH2CH2 |
| 119 | | NH2 | H | neopentyl | N(Ac)CH2CH2 |
| 120 | | NH2 | H | neopentyl | N(Bz)CH2CH2 |
| 121 | | NH2 | H | neopentyl | N(Me)CH2CH2 |
| 122 | | NH2 | H | neopentyl | N(Bn)CH2CH2 |
| 123 | | NH2 | H | neopentyl | NHOCH2 |
| 124 | | NH2 | H | neopentyl | NHOCH2CH2 |
| 125 | | NH2 | H | neopentyl | NHOCH2CF2 |
| 126 | | NH2 | H | neopentyl | NHSO2CH2 |
| 127 | | NH2 | H | neopentyl | N(Me)COCH2 |
| 128 | | NH2 | H | neopentyl | N(Bn)COCH2 |
| 129 | | NH2 | H | neopentyl | NHOCH2 |
| 130 | | NH2 | H | neopentyl | CH2CH2CH(OH) |
| 131 | | NH2 | H | neopentyl | CH2CH2CH(CO2H) |
| 132 | | NH2 | H | neopentyl | CH2CH2CH(SO3H) |

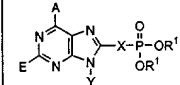
| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|---|--|-----------------------------------|
| 133 | | NH2 | H | neopentyl | CH2CH2CH(PO3H2) |
| 134 | 20.1 | NH2 | H | neopentyl | CH2-(1,2-imidazyl) |
| 135 | | NH2 | H | neopentyl | CH2-(1,2-pyrrolyl) |
| 136 | | NH2 | H | neopentyl | CSNHCH2 |
| 137 | | NH2 | H | neopentyl | 2,5-tetrahydrofuryl |
| 138 | | NH2 | H | neopentyl | 2,5-pyrrolidinyl |
| 139 | | NH2 | H | neopentyl | 3,4-dihydroxy-2,5-tetrahydrofuryl |
| 140 | | NH2 | H | neopentyl | 2,4-furyl |
| 141 | | NH2 | H | neopentyl | 4,2-furyl |
| 142 | | NH2 | H | neopentyl | 2,5-thienyl |
| 143 | | NH2 | H | neopentyl | 2,4-thienyl |
| 144 | | NH2 | H | neopentyl | 4,2-thienyl |
| 145 | | NH2 | H | neopentyl | 2,5-pyrrolyl |
| 146 | | NH2 | H | neopentyl | 2,5-imidazyl |
| 147 | | NH2 | H | neopentyl | 5,2-imidazyl |
| 148 | | NH2 | H | neopentyl | 2,5-oxazyl |
| 149 | | NH2 | H | neopentyl | 5,2-oxazyl |
| 150 | 12.1 | NH2 | H | neopentyl | 3,4-dichloro-2,5-furyl |
| 151 | | NH2 | H | neopentyl | 3-chloro-2,5-furyl |
| 152 | | NH2 | H | neopentyl | 4-chloro-2,5-furyl |
| 153 | | NH2 | H | neopentyl | 3,4-fluoro-2,5- |

| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|------------|--|----------------------|
| | | | | | furanyl |
| 154 | | NH2 | H | neopentyl | 3-fluoro-2,5-furanyl |
| 155 | | NH2 | H | neopentyl | 4-fluoro-2,5-furanyl |
| 156 | | NH2 | H | neopentyl | CONHCH(CO2H) |
| 157 | | NH2 | Me | neopentyl | 2,5-furanyl |
| 158 | | NH2 | Et | neopentyl | 2,5-furanyl |
| 159 | | NH2 | Pr | neopentyl | 2,5-furanyl |
| 160 | | NH2 | vinyl | neopentyl | 2,5-furanyl |
| 161 | | NH2 | acetylenyl | neopentyl | 2,5-furanyl |
| 162 | | NH2 | allyl | neopentyl | 2,5-furanyl |
| 163 | | NH2 | 2-furanyl | neopentyl | 2,5-furanyl |
| 164 | | NH2 | 3-furanyl | neopentyl | 2,5-furanyl |
| 165 | | NH2 | 2-thienyl | neopentyl | 2,5-furanyl |
| 166 | | NH2 | 3-thienyl | neopentyl | 2,5-furanyl |
| 167 | | NH2 | Ph | neopentyl | 2,5-furanyl |
| 168 | 22.1 | NH2 | NH2 | neopentyl | 2,5-furanyl |
| 169 | | NH2 | NHMe | neopentyl | 2,5-furanyl |
| 170 | | NH2 | N(Me)2 | neopentyl | 2,5-furanyl |
| 171 | | NH2 | NHBn | neopentyl | 2,5-furanyl |
| 172 | | NH2 | I | neopentyl | 2,5-furanyl |
| 173 | | NH2 | Br | neopentyl | 2,5-furanyl |
| 174 | | NH2 | Cl | neopentyl | 2,5-furanyl |
| 175 | | NH2 | F | neopentyl | 2,5-furanyl |
| 176 | | NH2 | OMe | neopentyl | 2,5-furanyl |
| 177 | | NH2 | OEt | neopentyl | 2,5-furanyl |
| 178 | | NH2 | OPr | neopentyl | 2,5-furanyl |
| 179 | | NH2 | SO2Me | neopentyl | 2,5-furanyl |

| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|--------|-----------|--|-------------|
| 180 | | NH2 | SEt | neopentyl | 2,5-furanyl |
| 181 | | NH2 | SPr | neopentyl | 2,5-furanyl |
| 182 | | NH2 | SBu | neopentyl | 2,5-furanyl |
| 183 | | NH2 | CN | neopentyl | 2,5-furanyl |
| 184 | | NH2 | CONH2 | neopentyl | 2,5-furanyl |
| 185 | | NH2 | 2-pyridyl | neopentyl | 2,5-furanyl |
| 186 | | NH2 | 3-pyridyl | neopentyl | 2,5-furanyl |
| 187 | | NH2 | 4-pyridyl | neopentyl | 2,5-furanyl |
| 188 | 5.4 | NH2 | H | 1-(3-cyclohexyl)propyl | CH2OCH2 |
| 189 | 5.3 | NH2 | H | 1-nonyl | CH2OCH2 |
| 190 | 5.2 | NH2 | H | 2-cyclohexylethyl | CH2OCH2 |
| 191 | 5.1 | NH2 | H | 2-phenethyl | CH2OCH2 |
| 192 | 10.2 | NHMe | H | 2-phenethyl | 2,5-furanyl |
| 193 | 10.1 | N(Me)2 | H | 2-phenethyl | 2,5-furanyl |
| 194 | 9.1 | Cl | H | 2-phenethyl | 2,5-furanyl |
| 195 | 11.1 | NH2 | SMe | isobutyl | 2,5-furanyl |
| 196 | 11.2 | NH2 | SO2Me | isobutyl | 2,5-furanyl |
| 197 | 4.1 | NH2 | H | D-ribosyl | NHCH2CH2 |
| 198 | 4.2 | NH2 | H | 5'-deoxy-D-ribosyl | NHCH2CH2 |
| 199 | | NH2 | H | H | NHCH2CH2 |
| 200 | 3.1 | NH2 | H | benzyl | NHCH2CH2 |
| 201 | 3.2 | NH2 | H | 2-phenethyl | NHCH2CH2 |
| 202 | 3.3 | NH2 | H | 2-naphthylmethyl | NHCH2CH2 |
| 203 | 6.2 | NH2 | H | 2-phenethyl | CH2CH2CH2 |
| 204 | 3.4 | NH2 | H | 2-cyclohexylethyl | NHCH2CH2 |
| 205 | 6.1 | NH2 | H | 2-cyclohexylethyl | CH2CH2CH2 |
| 206 | 8.1 | NH2 | H | 2-cyclohexylethyl | SCH2 |
| 207 | 7.1 | NH2 | H | 2-phenethyl | 2,5-thienyl |
| 208 | | NH2 | Me | isobutyl | 2,5-furanyl |

| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|-----------|--|-------------|
| 209 | | NH2 | Et | isobutyl | 2,5-furanyl |
| 210 | | NH2 | SEt | isobutyl | 2,5-furanyl |
| 211 | | NH2 | SPr | isobutyl | 2,5-furanyl |
| 212 | | NH2 | 2-furanyl | isobutyl | 2,5-furanyl |
| 213 | | NH2 | 2-thienyl | isobutyl | 2,5-furanyl |
| 214 | | NH2 | Pr | isobutyl | 2,5-furanyl |
| 215 | | NH2 | F | isobutyl | 2,5-furanyl |
| 216 | | NH2 | Cl | isobutyl | 2,5-furanyl |
| 217 | | NH2 | Br | isobutyl | 2,5-furanyl |
| 218 | | NH2 | H | isobutyl | 2,5-furanyl |
| 219 | | NH2 | Et | isobutyl | CONHCH2 |
| 220 | | NH2 | SEt | isobutyl | CONHCH2 |
| 221 | | NH2 | SPr | isobutyl | CONHCH2 |
| 222 | | NH2 | 2-furanyl | isobutyl | CONHCH2 |
| 223 | | NH2 | 2-thienyl | isobutyl | CONHCH2 |
| 224 | | NH2 | Pr | isobutyl | CONHCH2 |
| 225 | | NH2 | F | isobutyl | CONHCH2 |
| 226 | | NH2 | Cl | isobutyl | CONHCH2 |
| 227 | | NH2 | Br | isobutyl | CONHCH2 |
| 228 | | NH2 | Me | isobutyl | CONHCH2 |
| 229 | | NH2 | H | isobutyl | CONHCH2 |
| 230 | | NH2 | Et | neopentyl | acetylene |
| 231 | | NH2 | SEt | neopentyl | acetylene |
| 232 | | NH2 | SPr | neopentyl | acetylene |
| 233 | | NH2 | 2-furanyl | neopentyl | acetylene |
| 234 | | NH2 | 2-thienyl | neopentyl | acetylene |
| 235 | | NH2 | Pr | neopentyl | acetylene |
| 236 | | NH2 | F | neopentyl | acetylene |
| 237 | | NH2 | Cl | neopentyl | acetylene |
| 238 | | NH2 | Br | neopentyl | acetylene |

| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|----------|-----------|--|-------------|
| 239 | | NH2 | Me | neopentyl | acetylene |
| 240 | | NH2 | Et | neopentyl | NHCOCH2 |
| 241 | | NH2 | SEt | neopentyl | NHCOCH2 |
| 242 | | NH2 | SPr | neopentyl | NHCOCH2 |
| 243 | | NH2 | 2-furanyl | neopentyl | NHCOCH2 |
| 244 | | NH2 | 2-thienyl | neopentyl | NHCOCH2 |
| 245 | | NH2 | Pr | neopentyl | NHCOCH2 |
| 246 | | NH2 | F | neopentyl | NHCOCH2 |
| 247 | | NH2 | Cl | neopentyl | NHCOCH2 |
| 248 | | NH2 | Br | neopentyl | NHCOCH2 |
| 249 | | NH2 | Me | neopentyl | NHCOCH2 |
| 250 | | NH2 | Et | neopentyl | CH2OCH2 |
| 251 | | NH2 | SEt | neopentyl | CH2OCH2 |
| 252 | | NH2 | SPr | neopentyl | CH2OCH2 |
| 253 | | NH2 | 2-furanyl | neopentyl | CH2OCH2 |
| 254 | | NH2 | 2-thienyl | neopentyl | CH2OCH2 |
| 255 | | NH2 | Pr | neopentyl | CH2OCH2 |
| 256 | | NH2 | F | neopentyl | CH2OCH2 |
| 257 | | NH2 | Cl | neopentyl | CH2OCH2 |
| 258 | | NH2 | Br | neopentyl | CH2OCH2 |
| 259 | | NH2 | Me | neopentyl | CH2OCH2 |
| 260 | | NHBn | H | neopentyl | 2,5-furanyl |
| 261 | | NHPh | H | neopentyl | 2,5-furanyl |
| 262 | | NHBn | SMe | neopentyl | 2,5-furanyl |
| 263 | | NHPh | SMe | neopentyl | 2,5-furanyl |
| 264 | | NHPh-4-F | H | neopentyl | 2,5-furanyl |
| 265 | | NHPh-4-F | SMe | neopentyl | 2,5-furanyl |
| 266 | | NHNH2 | F | neopentyl | 2,5-furanyl |
| 267 | | NH2 | Me | cyclopropylmethyl | 2,5-furanyl |
| 268 | | NH2 | SMe | cyclopropylmethyl | 2,5-furanyl |

| Table Compound No. | Synthetic Example No. | | |  | |
|--------------------|-----------------------|-----|-----|--|-------------|
| 269 | | NH2 | F | cyclopropylmethyl | 2,5-furanyl |
| 270 | | NH2 | Cl | cyclopropylmethy | 2,5-furanyl |
| 271 | | NH2 | Br | cyclopropylmethyl | 2,5-furanyl |
| 272 | | NH2 | Et | cyclopropylmethyl | 2,5-furanyl |
| 273 | | NH2 | CN | cyclopropylmethyl | 2,5-furanyl |
| 274 | | NH2 | Me | cyclopropylmethyl | CONHCH2 |
| 275 | | NH2 | SMe | cyclopropylmethyl | CONHCH2 |
| 276 | | NH2 | F | cyclopropylmethyl | CONHCH2 |
| 277 | | NH2 | Cl | cyclopropylmethy | CONHCH2 |
| 278 | | NH2 | Br | cyclopropylmethyl | CONHCH2 |
| 279 | | NH2 | Et | cyclopropylmethyl | CONHCH2 |
| 280 | | NH2 | CN | cyclopropylmethyl | CONHCH2 |
| 281 | | NH2 | Me | cyclopropylmethyl | NHCOCH2 |
| 282 | | NH2 | SMe | cyclopropylmethyl | NHCOCH2 |
| 283 | | NH2 | F | cyclopropylmethyl | NHCOCH2 |
| 284 | | NH2 | Cl | cyclopropylmethy | NHCOCH2 |
| 285 | | NH2 | Br | cyclopropylmethyl | NHCOCH2 |
| 286 | | NH2 | Et | cyclopropylmethyl | NHCOCH2 |
| 287 | | NH2 | CN | cyclopropylmethyl | NHCOCH2 |
| 288 | 2.18 | NH2 | H | 3-(1-imidazolylpropyl) | 2,5-furanyl |
| 289 | 19.1 | NH2 | H | neopentyl | 1,2-C6H4-O- |
| 290 | 21.1 | NH2 | H | 2-phenethyl | CONHCH2 |

More preferred are the following compounds from Table 1 including salts and prodrugs thereof:

1, 21, 22, 23, 29, 50, 57, 61, 62, 63, 66, 67, 72, 73, 89, 90, 107, 110, 111, 112, 113, 114,
115, 119, 123, 125, 126, 129, 130, 131, 132, 133, 134, 136, 137, 145, 148, 149, 151,
152, 153, 154, 155, 156, 158, 159, 163, 165, 173, 174, 175, 180, 181, 182, 183, 209,
210, 212, 215, 216, 217, 219, 220, 221, 230, 231, 234, 236, 237, 238, 240, 241, 246,
5 247, 248, 250, 251, 256, 257, 258, 266, 268, 269, and 272.

Most preferred are the following compounds and their salts and prodrugs:

N⁹-neopentyl-2-methylthio-8-phosphonomethylaminocarbonyladenine;
N⁹-neopentyl-2-methylthio-8-(2-(5-phosphono)furanyl)adenine;
N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine;

10 N⁹-isobutyl-2-methylthio-8-(2-(5-phosphono)furanyl)adenine;
N⁹-isobutyl-8-(2-(5-phosphono)furanyl)adenine;
N⁹-cyclopropyl-8-(2-(5-phosphono)furanyl)adenine;
N⁹-(2-cyclohexyl)ethyl-8-(2-(5-phosphono)furanyl)adenine;
N⁹-(1-(2,2-dimethyl-3-chloro)propyl)-8-(2-(5-phosphono)furanyl)adenine;

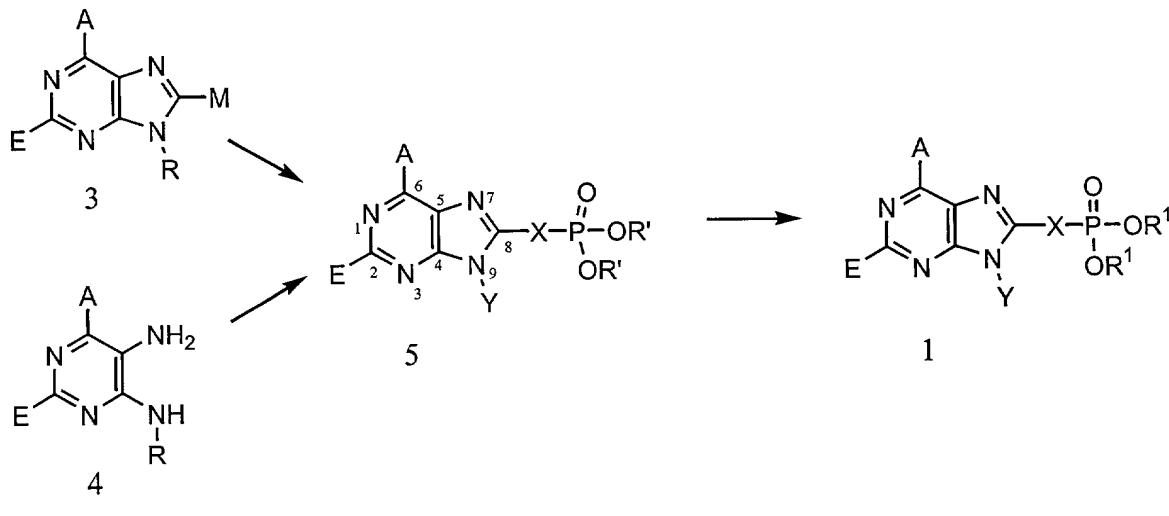
15 N⁹-(1-(3,3-dimethyl)butyl)-8-(2-(5-phosphono)furanyl)adenine;
N⁹-(1,5,5-trimethyl-3-cyclohexen-1-yl)methyl-8-(2-(5-phosphono)furanyl)adenine;
N⁹-neopentyl-8-(2-phosphonoacetylene-1-yl)adenine;
N⁹-neopentyl-8-(1-(3-phosphono-3-sulfuryl)propyl)adenine;
N⁹-neopentyl-8-(1-(3-phosphono-3-carboxyl)propyl)adenine;

20 N⁹-neopentyl-8-(1-(3,3-diphosphono)propyl)adenine;
N⁹-neopentyl-2-chloro-8-(2-(5-phosphono)furanyl)adenine;
2-Ethyl-N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine;
2-Methylthio-N⁹-isobutyl-8-(2-(5-phosphono)furanyl)adenine; and
2-Methylthio-N⁹-isobutyl-8-(phosphonomethoxymethyl)adenine.

25 Synthesis of Compounds of Formula 1

Synthesis of compounds encompassed by the present invention typically includes some or all of the following general steps: (1) preparation of phosphonate prodrug; (2) deprotection of phosphonate ester; (3) modification of C-8-substituted

purine intermediates; (4) modification of purine at positions other than C-8; (5) construction of the purine ring system; and (6) preparation of 4,5-diaminopyrimidine and other coupling partners.



(1) Preparation of phosphonate prodrugs

Prodrug esters can be introduced at different stages of the synthesis. Because of their lability, prodrugs are often prepared from compounds of formula 1 where R¹ is H. Advantageously, these prodrug esters can be introduced at an early stage, provided that 10 it can withstand the reaction conditions of the subsequent steps.

Compounds of formula 5 where R¹ is H, can be alkylated with electrophiles (such as alkyl halides, alkyl sulfonates etc) under nucleophilic substitution reaction conditions to give phosphonate esters. For example prodrugs of formula 1, where R¹ is acyloxymethyl group can be synthesized through direct alkylation of the free phosphonic acid of formula 5, with the desired acyloxymethyl halide (e.g. Cl, Br, I; Elhaddadi, et al *Phosphorus Sulfur*, 1990, 54(1-4): 143; Hoffmann, *Synthesis*, 1988, 62) in presence of base e.g. N, N'-dicyclohexyl-4-morpholinecarboxamidine, Hunigs base etc. in polar aprotic solvents such as DMF (Starrett, et al, *J. Med. Chem.*, 1994, 37, 1857). These carboxylates include but not limited to acetate, propionate, isobutyrate, pivalate, 20 benzoate, and other carboxylates. Alternately, these acyloxymethylphosphonate esters

can also be synthesized by treatment of the nitrophosphonic acid (A is NO_2 in formula 5; Dickson, et al, *J. Med. Chem.*, **1996**, *39*: 661; Iyer, et al, *Tetrahedron Lett.*, **1989**, *30*: 7141; Srivastva, et al, *Bioorg. Chem.*, **1984**, *12*: 118). This can be extended to many other types of prodrugs, such as compounds of formula 1 where R^1 is 3-phthalidyl, 2-

5 oxo-4,5-dihydro-1,3-dioxolanemethyl, and 2-oxotetrahydrofuran-5-yl groups, etc. (Biller and Magnin (US 5,157,027); Serafinowska et al. (*J. Med. Chem.* **38**: 1372 (1995)); Starrett et al. (*J. Med. Chem.* **37**: 1857 (1994)); Martin et al. *J. Pharm. Sci.* **76**: 180 (1987); Alexander et al., *Collect. Czech. Chem. Commun.*, **59**: 1853 (1994)); and EPO 0632048A1). N,N-Dimethylformamide dialkyl acetals can also be used to alkylate 10 phosphonic acids (Alexander, P., et al *Collect. Czech. Chem. Commun.*, **1994**, *59*, 1853).

Alternatively, these phosphonate prodrugs or phosphoramidates can also be synthesized, by reaction of the corresponding dichlorophosphonates and an alcohol or an amine (Alexander, et al, *Collect. Czech. Chem. Commun.*, **1994**, *59*: 1853). For example, the reaction of dichlorophosphonate with phenols and benzyl alcohols in the presence of base (such as pyridine, triethylamine, etc) yields compounds of formula 1 where R^1 is aryl (Khamnei, S., et al *J. Med. Chem.*, **1996**, *39*: 4109; Serafinowska, H.T., et al *J. Med. Chem.*, **1995**, *38*: 1372; De Lombaert, S., et al *J. Med. Chem.*, **1994**, *37*: 498) or benzyl (Mitchell, A.G., et al *J. Chem. Soc. Perkin Trans. 1*, **1992**, *38*: 2345).

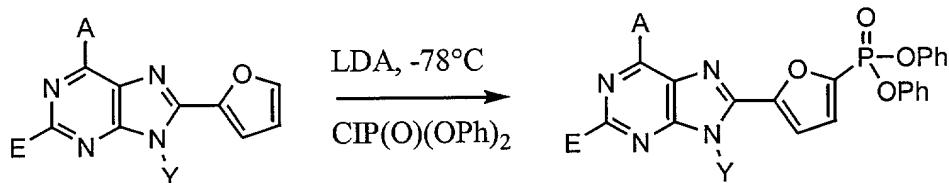
20 The disulfide-containing prodrugs, reported by Puech et al., *Antiviral Res.*, **1993**, *22*: 155, can also be prepared from dichlorophosphonate and 2-hydroxyethyl disulfide under the standard conditions.

Such reactive dichlorophosphonate intermediates, can be prepared from the corresponding phosphonic acids and the chlorinating agents e.g. thionyl chloride 25 (Starrett, et al, *J. Med. Chem.*, **1994**, 1857), oxalyl chloride (Stowell, et al, *Tetrahedron Lett.*, **1990**, *31*: 3261), and phosphorus pentachloride (Quast, et al, *Synthesis*, **1974**, 490). Alternatively, these dichlorophosphonates can also be generated from disilyl phosphonate esters (Bhongle, et al, *Synth. Commun.*, **1987**, *17*: 1071) and dialkyl

phosphonate esters (Still, et al, *Tetrahedron Lett.*, **1983**, *24*: 4405; Patois, et al, *Bull. Soc. Chim. Fr.*, **1993**, *130*: 485).

Furthermore, these prodrugs can be prepared from Mitsunobu reactions (Mitsunobu, *Synthesis*, **1981**, *1*; Campbell, *J.Org. Chem.*, **1992**, *52*: 6331), and other acid coupling reagents include, but not limited to, carbodiimides (Alexander, et al, *Collect. Czech. Chem. Commun.*, **1994**, *59*: 1853; Casara, et al, *Bioorg. Med. Chem. Lett.*, **1992**, *2*: 145; Ohashi, et al, *Tetrahedron Lett.*, **1988**, *29*: 1189), and benzotriazolyloxytris-(dimethylamino)phosphonium salts (Campagne, et al, *Tetrahedron Lett.*, **1993**, *34*: 6743). The prodrugs of formula 1 where R¹ is the cyclic carbonate or lactone or phthalidyl can also be synthesized by direct alkylation of free phosphonic acid with desired halides in the presence of base such as NaH or diisopropylethylamine (Biller and Magnin US 5,157,027; Serafinowska et al. *J. Med. Chem.* **38**: 1372 (1995); Starrett et al. *J. Med. Chem.* **37**: 1857 (1994); Martin et al. *J. Pharm. Sci.* **76**: 180 (1987); Alexander et al., *Collect. Czech. Chem. Commun.*, **59**: 1853 (1994); and EPO 0632048A1).

R¹ can also be introduced at an early stage of synthesis, when feasible. For example, compounds of formula 1 where R¹ is phenyl can be prepared by phosphorylation of 2-furanylpurines via strong base treatment (e.g. LDA) followed by chlorodiphenylphosphonate, as shown in the following scheme. Alternatively, such compounds can be prepared by cyclization of 5-diphenylphosphono-2-furaldehyde with 4,5-diaminopyrimidines as described in section 5.



It is envisioned that compounds of formula 1 can be mixed phosphonate esters by combining the above described prodrugs (e.g. phenyl benzyl phosphonate esters, phenyl acyloxyalkyl phosphonate esters, etc.). For example, the chemically combined

phenyl-benzyl prodrugs are reported by Meier et al. *Bioorg. Med. Chem. Lett.*, **1997**, 7: 99.

The substituted cyclic propyl phosphonate esters of formula 5, can be synthesized by reaction of the corresponding dichlorophosphonate and the substituted 5 1,3-propanediol. The following are some of the methods to prepare the substituted 1,3-propanediols.

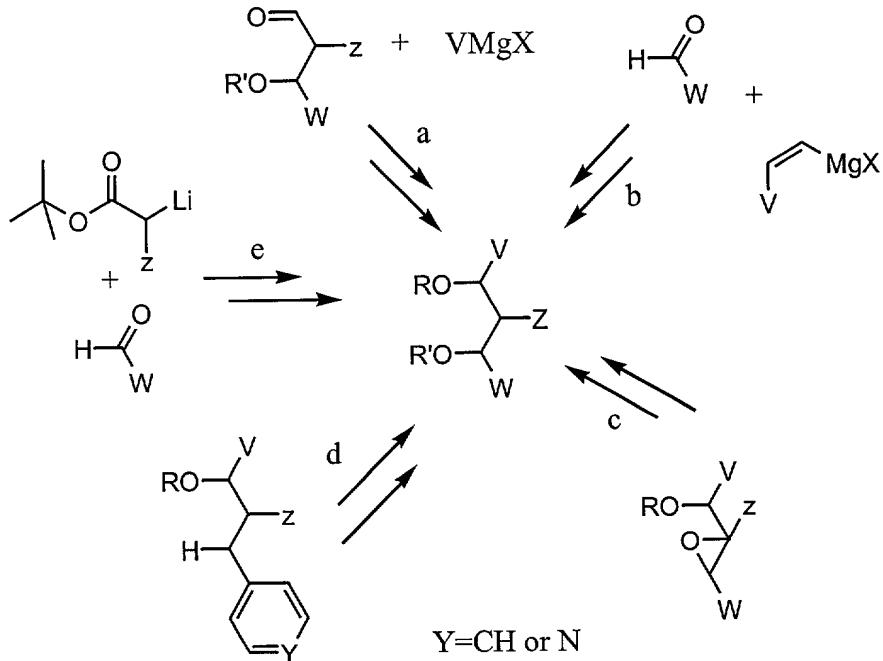
Synthesis of the 1,3-Propanediols Used in the Preparation of Certain Prodrugs

The discussion of this step includes various synthetic methods for the preparation of the following types of propane-1,3-diols: i) 1-substituted; ii) 10 2-substituted; and iii) 1,2- or 1,3-annulated. Different groups on the prodrug part of the molecule *i.e.*, on the propanediol moiety can be introduced or modified either during the synthesis of the diols or after the synthesis of the prodrugs.

i) 1-Substituted 1,3-Propanediols

Propane-1,3-diols can be synthesized by several well known methods in the literature. Aryl Grignard additions to 1-hydroxypropan-3-al gives 1-aryl-substituted 15 propane-1,3-diols (path a). This method will enable conversion of various substituted aryl halides to 1-arylsubstituted-1,3-propanediols (Coppi, et. al., *J. Org. Chem.*, **1988**, 53, 911). Aryl halides can also be used to synthesize 1-substituted propanediols by Heck coupling of 1,3-diox-4-ene followed by reduction and hydrolysis (Sakamoto, et. 20 al., *Tetrahedron Lett.*, **1992**, 33, 6845). A variety of aromatic aldehydes can be converted to 1-substituted-1,3-propanediols by vinyl Grignard addition followed by hydroboration (path b). Substituted aromatic aldehydes are also utilized by lithium-t-butylacetate addition followed by ester reduction (path e) (Turner., *J. Org. Chem.*, **1990**, 55 4744). In another method, commercially available cinnamyl alcohols can be 25 converted to epoxy alcohols under catalytic asymmetric epoxidation conditions. These epoxy alcohols are reduced by Red-AI to result in enantiomerically pure propane-1,3-diols (path c). Alternatively, enantiomerically pure 1,3-diols can be obtained by chiral borane reduction of hydroxyethyl aryl ketone derivatives (Ramachandran, et. al.,

Tetrahedron Lett., 1997, 38 761). Pyridyl, quinoline, and isoquinoline propan-3-ol derivatives can be oxygenated to 1-substituted propan-1,3-diols by N-oxide formation followed by rearrangement under acetic anhydride conditions (path d) (Yamamoto, et. al., *Tetrahedron*, 1981, 37, 1871).

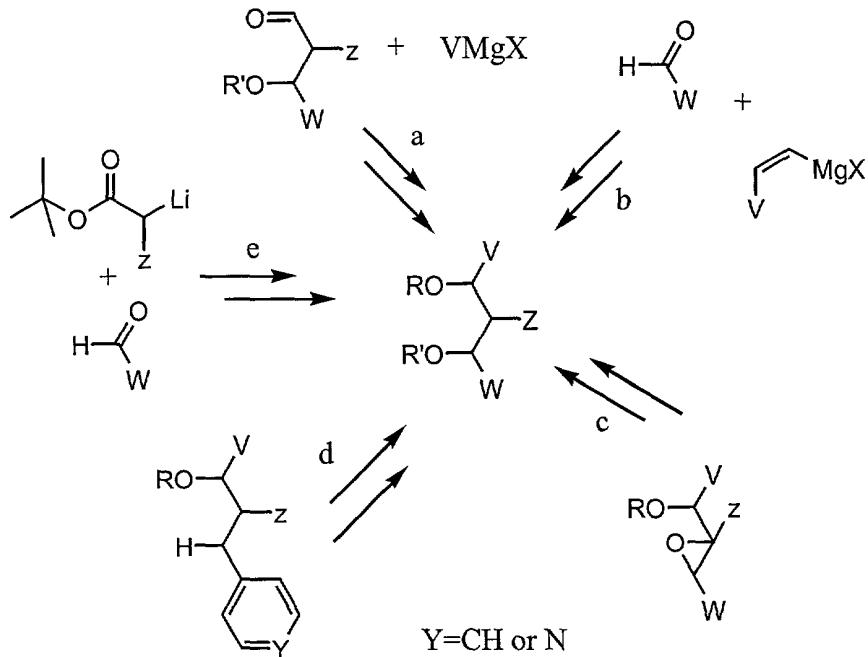


5

ii) 2-Substituted 1,3-Propanediols:

Various 2-substituted propane-1,3-diols can be made from commercially available 2-(hydroxymethyl)-1,3-propanediol. Triethyl methanetricarboxylate can be converted to the triol by complete reduction (path a) or diol-monocarboxylic acid derivatives can be obtained by partial hydrolysis and diester reduction (Larock, 10 *Comprehensive Organic Transformations*, VCH, New York, 1989). Nitrotriol is also known to give the triol by reductive elimination (path b) (Latour, et. al., *Synthesis*, 1987, 8, 742). The triol can be derivatized as a mono acetate or carbonate by treatment with alkanoyl chloride, or alkylchloroformate, respectively (path d) (Greene and Wuts, 15 *Protective Groups in Organic Synthesis*, John Wiley, New York, 1990). Aryl substitution can be made by oxidation to the aldehyde followed by aryl Grignard

additions (path c) and the aldehyde can also be converted to substituted amines by reductive amination reactions (path e).



iii) Annulated 1,3-Propanediols:

5 Prodrugs of formula 1 where V - Z or V - W are fused by three carbons are made from cyclohexanediol derivatives. Commercially available *cis*, *cis*-1,3,5-cyclohexanetriol can be used for prodrug formation. This cyclohexanetriol can also be modified as described in the case of 2-substituted propane-1,3-diols to give various analogues. These modifications can either be made before or after formation of

10 prodrugs. Various 1,3-cyclohexanediols can be made by Diels-Alder methodology using pyrone as the diene (Posner, et. al., *Tetrahedron Lett.*, 1991, 32, 5295). Cyclohexyl diol derivatives are also made by nitrile oxide olefin-additions (Curran, et. al., *J. Am. Chem. Soc.*, 1985, 107, 6023). Alternatively, cyclohexyl precursors can be made from quinic acid (Rao, et. al., *Tetrahedron Lett.*, 1991, 32, 547.)

(2) Deprotection of Phosphonate Esters

Compounds of formula 1 where R¹ is H may be prepared from phosphonate esters using known phosphate and phosphonate ester cleavage conditions. For example, alkyl phosphonate esters are generally cleaved by reaction with silyl halides followed by hydrolysis of the intermediate silyl phosphonate esters. Depending on the stability of the products, these reactions are usually accomplished in the presence of acid scavengers such as 1,1,1,3,3-hexamethyldisilazane, 2,6-lutidine, etc. Various silyl halides can be used for this transformation, such as chlorotrimethylsilane (Rabinowitz *J. Org. Chem.*, 1963, 28: 2975), bromotrimethylsilane (McKenna et al. *Tetrahedron Lett.*, 1977, 155), iodotrimethylsilane (Blackburn et al. *J. Chem. Soc., Chem. Commun.*, 1978, 870). Phosphonate esters can also be cleaved under strong acid conditions, such as hydrogen halides in acetic acid or water, and metal halides (Moffatt et al. *U.S. Patent 3,524,846*, 1970). Phosphonate esters can also be converted to dichlorophosphonates with halogenating agents (e.g. PCl₅, SOCl₂, BBr₃, etc. Pelchowicz et al. *J. Chem. Soc.*, 1961, 238) and subsequently hydrolyzed to give phosphonic acids. Reductive reactions are useful in cleaving aryl and benzyl phosphonate esters. For example, aryl and benzyl phosphonate esters can be cleaved under hydrogenolysis conditions (Lejczak et al. *Synthesis*, 1982, 412; Elliott et al. *J. Med Chem.*, 1985, 28: 1208.) or dissolving metal reduction conditions (Shafer et al. *J. Am. Chem. Soc.*, 1977, 99: 5118). (Elliott et al. *J. Med. Chem.*, 1985, 28: 1208). Electrochemical (Shono et al. *J. Org. Chem.*, 1979, 44: 4508) and pyrolysis (Gupta et al. *Synth. Commun.*, 1980, 10: 299) conditions have also been used to cleave various phosphonate esters.

(3) Modification of C-8-substituted Purine Intermediates

8-Substituted purines are useful intermediates in the preparation of compounds of formula 1. 8-Halopurines, which are particularly useful intermediates, are readily prepared using chemistry well described in the literature. For example, N⁹-alkyladenines are halogenated at the C-8 position using known halogenating agents (e.g. Br₂, NBS). 8-Alkylpurine can be prepared through direct lithiation of purine followed

by trapping with electrophiles (e.g. alkyl halides, Barton et al. *Tetrahedron Lett.*, 1979, 5877).

Functionaliztion of 8-halopurines can be accomplished under substitution reaction conditions with nucleophiles such as amines, alcohols, azides, sulfides, and 5 alkylthiols. It is advantageous to have the phosphonate moiety as part of the nucleophiles. For example, substitution of 8-bromopurine with aminoalkylphosphonates gives compounds of formula 1 where X is alkylamino.

8-Halopurines can also be transformed into other 8-substituted purines using palladium catalyzed reactions (*Heck Palladium Reagents in Organic Synthesis*;

10 Academic Press: San Diego, 1985). For example, palladium catalyzed carbonylation reactions of 8-bromopurine in the presence of alcohol gives 8-alkoxycarbonylpurines. Using known chemistry, the 8-carboxylate group can be converted into other functional groups, such as hydroxymethyl, halomethyl, formyl, carboxylic acid, carbamoyl, and thiocarbonyl groups. These functional groups are useful intermediates for the synthesis 15 of compounds of formula 1. For example, 8-alkyl and 8-arylpurines can be prepared from 8-halopurines via palladium catalyzed coupling reactions with organotin (Moriarty et al. *Tetrahedron Lett.*, 1990, 41: 5877), organoborane (Yatagai, *Bull. Chem. Soc. Jpn.*, 1980, 53: 1670), and other reagents known to couple with aryl halides. When the coupling reagents contain the dialkylphosphonate group, the reaction is useful for 20 preparation of compounds of formula 5 where X is alkyl, alkenyl, alkynyl, and aryl. For example, 8-bromopurine can be coupled with diethyl 1-tributylstannyl-3-allylphosphonate to give compounds of formula 5 where X is -CH=CHCH₂-.

Subsequent hydrogenation reaction gives compounds of formula 5 where X is -CH₂CH₂CH₂-.

25 The phosphonate group can also be introduced by further modification of the 8-substituents. Substitutions of 8-haloalkyl or 8-sulfonylalkylpurine with nucleophiles containing the phosphonate group are useful for the preparation of compounds of formula 5 where X is alkylaminoalkyl, alkoxyalkyl, and alkylthioalkyl. For example,

compounds of formula 5 where X is -CH₂OCH₂- can be prepared from 8-bromomethylpurine using hydroxymethylphosphonate esters and a suitable base. It is possible to reverse the nature of the nucleophiles and electrophiles for the substitution reactions, i.e. haloalkyl- and/or sulfonylalkylphosphonate esters can be substituted with

5 purines containing a nucleophile at the C-8 position (such as 8-hydroxyalkyl, 8-thioalkyl, and 8-aminoalkylpurines). For example, diethyl phosphonomethyltriflate can be substituted by alcohols such as 8-hydroxymethylpurine to give compounds of formula 5 where X is -CH₂OCH₂- (Phillion et al. *Tetrahedron Lett.* **1986**, 27: 1477).

Known amide formation reactions are useful for the synthesis of compounds of formula

10 5 where X is alkylaminocarbonyl, alkoxy carbonyl, alkoxythiocarbonyl, and alkylthiocarbonyl. For example, coupling of 8-purinecarboxylic acids with aminoalkylphosphonate esters gives compounds of formula 5 where X is alkylaminocarbonyl. For compounds of formula 5 where X is alkyl, the phosphonate group can also be introduced using other common phosphonate formation methods,

15 such as Michaelis-Arbuzov reaction (Bhattacharya et al. *Chem. Rev.*, 1981, 81: 415), Michaelis-Becker reaction (Blackburn et al. *J. Organomet. Chem.*, 1988, 348: 55), addition reactions of phosphorus to electrophiles (such as aldehydes, ketones, acyl halides, imines and other carbonyl derivatives).

8-Azidopurines are useful for the preparation for compounds of formula 5 where 20 X is alkylamino and alkylcarbonylamino groups. For example, carboxylic acids (e.g. (RO)₂P(O)-alkyl-CO₂H) can be directly coupled to 8-azidopurines to give 8-alkylcarbonylaminopurines (Urpi et al. *Tetrahedron Lett.*, 1986, 27: 4623). Alternatively, 8-azidopurines can also be converted to 8-aminopurines under reductive conditions, and subsequently converted to 8-alkylaminocarbonyl- and 8-alkylaminopurines using known chemistry.

(4) Modification of purines at positions other than C-8

Compounds of formula 5 can be further modified to give intermediates useful for the synthesis of compounds of formula 1. For example, substitution reactions of 6-

chloropurine by ammonia or alkylamines are useful for the preparations of compounds of formula 5 where A is amino and alkylamino groups.

E groups can be introduced by modifying existing 2-substituents of purine. For example, 2-halopurines, readily accessible from 2-aminopurines via chemistry well described in the literature, can be converted to other 2-substituted purines by, for example, nucleophilic substitution reactions; transition metal catalyzed reactions, etc. (J. Med. Chem., 1993, 36: 2938; Heterocycles, 1990, 30: 435).

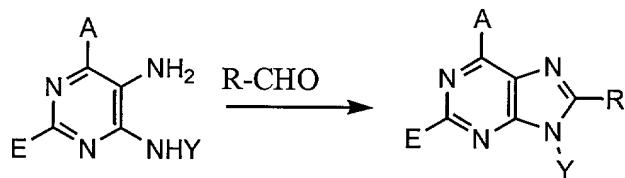
E groups can also be introduced via metalation (e.g. lithiation, J. Org. Chem., 1997, 62(20), 6833) of the C-2-position and followed by addition of electrophiles which can be the desired E group or a substituent (e.g. tributylstannyl group) which can be converted to the desired E group using conventional chemistry.

It is envisioned that N⁹-substituted purines can be readily prepared from compounds of formula 5 where Y is H using, for example, standard alkylation reactions (with alkyl halide, or sulfonate), or Mitsunobu reactions. Further elaborations of substituents on Y are also possible.

More importantly, combinatorial methods have been developed for synthesis of 2- and N-9-substituted purines on solid-phase which conceivably can be applied for the synthesis of purine FBPase inhibitors (Schultz, et al, Tetrahedron Lett., 1997, 38(7), 1161; J. Am. Chem. Soc., 1996, 118, 7430).

20 (5) Construction of the Purine Ring System

The purine ring system of compounds of formula 1 can be constructed using 4,5-diaminopyrimidines and carboxylates or their derivatives (such as aldehydes, amides, nitriles, ortho esters, imidates, etc.) (Townsend *Chemistry of Nucleosides and Nucleotides, Vol 1*; Plenum Press, New York and London, page 156-158). For example, alkyl and aryl aldehydes can be cyclized with 4,5-diaminopyrimidines as shown below.



Intramolecular cyclization reactions of pyrimidine derivatives can also be used to construct the purine ring system. For example, 5-acylamino-4-alkylaminopyrimidines are treated with phosphorus oxychloride and cyclized under

5 basic conditions to give purine derivatives. This transformation can also be achieved using other reagents (e.g. $\text{SiCl}_4\text{-Et}_3\text{N}$, Desaubry et al. *Tetrahedron Lett.*, **1995**, *36*: 4249). Imidazole derivatives are also useful for the construction of purine ring system via cyclization reactions to form the pyrimidine ring (Townsend *Chemistry of Nucleosides and Nucleotides*, Vol 1; Plenum Press, New York and London, page 148-

10 156).

(6) Preparation of Diaminopyrimidine and Other Coupling Partners

Compounds of formula 4 are useful for the construction of purine ring systems, and such compounds can be readily synthesized using known chemistry. For example, the Y group can be introduced using a nucleophilic substitution reaction involving an 15 amine and 4-halopyrimidines (*Tetrahedron*, **1984**, *40*: 1433). Alternatively, palladium catalyzed reactions (Wolfe et al. *J. Am. Chem. Soc.*, **1996**, *118*: 7215) can also be used. Reductive amination reactions (*Synthesis*, **1975**, 135) and alkylation with electrophiles (such as halides, sulfonates) are useful for the preparation of compounds of formula 4 from 4-aminopyrimidines. The 5-amino group can be introduced using amine

20 formation reactions such as nitration followed by reduction (Dhainant et al. *J. Med. Chem.*, **1996**, *39*: 4099), arylazo compound formation followed by reduction (Lopez et al. *Nucleosides & Nucleotides*, **1996**, *15*: 1335), azide formation followed by reduction, or by rearrangement of carboxylic acid derivatives (e.g. Schmidt, Curtius, and Beckmann reactions).

Coupling of aromatic or aliphatic aldehydes, and carboxylic acid derivatives with attached phosphonate esters are particularly suited for the preparation of compounds of formula 1 as described in section 5. Such phosphonate esters are prepared by lithiation of the aromatic ring using methods well described in literature

5 (Gschwend *Org. React.* 1979, 26: 1) followed by addition of phosphorylating agents (e.g. ClPO₃R₂). Phosphonate esters can also be introduced by Arbuzov-Michaelis reaction (Brill *Chem Rev.*, 1984, 84: 577) and transition metal catalyzed reaction with alkyl halides and aryl halides or triflates (Balthazar et al. *J. Org. Chem.*, 1980, 45: 5425; Petrakis et al. *J. Am. Chem. Soc.*, 1987, 109: 2831; Lu et al. *Synthesis*, 1987, 726).

10 Alternatively, aryl phosphonate esters can be prepared from aryl phosphates under anionic rearrangement conditions (Melvin *Tetrahedron Lett.*, 1981, 22: 3375; Casteel et al. *Synthesis*, 1991, 691). Aryl phosphate esters can also be used to prepare compounds of Formula 1 where X is an oxyaryl group. N-Alkoxy aryl salts with alkali metal derivatives of dialkyl phosphonate can be used to synthesize heteroaryl-2-phosphonate esters (Redmore *J. Org. Chem.*, 1970, 35: 4114).

15

A second lithiation step can be used to incorporate the aldehyde functionality, although other methods known to generate aromatic aldehydes can be envisioned as well (e.g. Vilsmeier-Hack reaction, Reimar-Tiemann reaction etc.). In the second lithiation step, the lithiated aromatic ring is treated with reagents that either directly

20 generate an aldehyde (e.g. DMF, HCO₂R, etc.) or with reagents that lead to a group that subsequently is transformed into an aldehyde group using known chemistry (e.g. alcohol, ester, cyano, alkene, etc.). It is also envisioned that the sequence of these reactions can be reversed, i.e. the aldehyde moiety can be incorporated first followed by the phosphorylation reaction. The order of the reaction will depend on the reaction

25 conditions and the protecting groups. Prior to the phosphorylation, it is also envisioned that it may be advantageous to protect the aldehydes using a number of well-known steps (hemiacetal, hemiaminal, etc.,). The aldehyde is then unmasked after

phosphorylation. (*Protective groups in Organic Synthesis*, Greene, T. W., 1991, Wiley, New York).

Formulations

Compounds of the invention are administered orally in a total daily dose of about 0.1 mg/kg/dose to about 100 mg/kg/dose, preferably from about 0.3 mg/kg/dose to about 30 mg/kg/dose. The most preferred dose range is from 0.5 to 10 mg/kg (approximately 1 to 20 nmoles/kg/dose). The use of time-release preparations to control the rate of release of the active ingredient may be preferred. The dose may be administered in as many divided doses as is convenient. When other methods are used (e.g. intravenous administration), compounds are administered to the affected tissue at a rate from 0.3 to 300 nmol/kg/min, preferably from 3 to 100 nmoles/kg/min. Such rates are easily maintained when these compounds are intravenously administered as discussed below.

For the purposes of this invention, the compounds may be administered by a variety of means including orally, parenterally, by inhalation spray, topically, or rectally in formulations containing pharmaceutically acceptable carriers, adjuvants and vehicles. The term parenteral as used here includes subcutaneous, intravenous, intramuscular, and intraarterial injections with a variety of infusion techniques. Intraarterial and intravenous injection as used herein includes administration through catheters. Oral administration is generally preferred.

Pharmaceutical compositions containing the active ingredient may be in any form suitable for the intended method of administration. When used for oral use for example, tablets, troches, lozenges, aqueous or oil suspensions, dispersible powders or granules, emulsions, hard or soft capsules, syrups or elixirs may be prepared.

Compositions intended for oral use may be prepared according to any method known to the art for the manufacture of pharmaceutical compositions and such compositions may contain one or more agents including sweetening agents, flavoring agents, coloring agents and preserving agents, in order to provide a palatable preparation. Tablets

containing the active ingredient in admixture with non-toxic pharmaceutically acceptable excipient which are suitable for manufacture of tablets are acceptable. These excipients may be, for example, inert diluents, such as calcium or sodium carbonate, lactose, calcium or sodium phosphate; granulating and disintegrating agents, such as

5 maize starch, or alginic acid; binding agents, such as starch, gelatin or acacia; and lubricating agents, such as magnesium stearate, stearic acid or talc. Tablets may be uncoated or may be coated by known techniques including microencapsulation to delay disintegration and adsorption in the gastrointestinal tract and thereby provide a sustained action over a longer period. For example, a time delay material such as

10 glyceryl monostearate or glyceryl distearate alone or with a wax may be employed.

Formulations for oral use may be also presented as hard gelatin capsules where the active ingredient is mixed with an inert solid diluent, for example calcium phosphate or kaolin, or as soft gelatin capsules wherein the active ingredient is mixed with water or an oil medium, such as peanut oil, liquid paraffin or olive oil.

15 Aqueous suspensions of the invention contain the active materials in admixture with excipients suitable for the manufacture of aqueous suspensions. Such excipients include a suspending agent, such as sodium carboxymethylcellulose, methylcellulose, hydroxypropyl methylcellulose, sodium alginate, polyvinylpyrrolidone, gum tragacanth and gum acacia, and dispersing or wetting agents such as a naturally occurring phosphatide (e.g., lecithin), a condensation product of an alkylene oxide with a fatty acid (e.g., polyoxyethylene stearate), a condensation product of ethylene oxide with a long chain aliphatic alcohol (e.g., heptadecaethyleneoxycetanol), a condensation product of ethylene oxide with a partial ester derived from a fatty acid and a hexitol anhydride (e.g., polyoxyethylene sorbitan monooleate). The aqueous suspension may

20 also contain one or more preservatives such as ethyl or n-propyl p-hydroxy-benzoate, one or more coloring agents, one or more flavoring agents and one or more sweetening agents, such as sucrose or saccharin.

25

Oil suspensions may be formulated by suspending the active ingredient in a vegetable oil, such as arachis oil, olive oil, sesame oil or coconut oil, or in a mineral oil such as liquid paraffin. The oral suspensions may contain a thickening agent, such as beeswax, hard paraffin or cetyl alcohol. Sweetening agents, such as those set forth above, and flavoring agents may be added to provide a palatable oral preparation.

5 These compositions may be preserved by the addition of an antioxidant such as ascorbic acid.

Dispersible powders and granules of the invention suitable for preparation of an aqueous suspension by the addition of water provide the active ingredient in admixture with a dispersing or wetting agent, a suspending agent, and one or more preservatives.

10 Suitable dispersing or wetting agents and suspending agents are exemplified by those disclosed above. Additional excipients, for example sweetening, flavoring and coloring agents, may also be present.

The pharmaceutical compositions of the invention may also be in the form of oil-in-water emulsions. The oily phase may be a vegetable oil, such as olive oil or arachis oil, a mineral oil, such as liquid paraffin, or a mixture of these. Suitable emulsifying agents include naturally-occurring gums, such as gum acacia and gum tragacanth, naturally occurring phosphatides, such as soybean lecithin, esters or partial esters derived from fatty acids and hexitol anhydrides, such as sorbitan monooleate, and

15 condensation products of these partial esters with ethylene oxide, such as polyoxyethylene sorbitan monooleate. The emulsion may also contain sweetening and flavoring agents.

Syrups and elixirs may be formulated with sweetening agents, such as glycerol, sorbitol or sucrose. Such formulations may also contain a demulcent, a preservative, a

20 flavoring or a coloring agent.

The pharmaceutical compositions of the invention may be in the form of a sterile injectable preparation, such as a sterile injectable aqueous or oleaginous suspension. This suspension may be formulated according to the known art using those

suitable dispersing or wetting agents and suspending agents which have been mentioned above. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent, such as a solution in 1,3-butane-diol or prepared as a lyophilized powder. Among the acceptable vehicles

5 and solvents that may be employed are water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile fixed oils may conventionally be employed as a solvent or suspending medium. For this purpose any bland fixed oil may be employed including synthetic mono- or diglycerides. In addition, fatty acids such as oleic acid may likewise be used in the preparation of injectables.

10 The amount of active ingredient that may be combined with the carrier material to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. For example, a time-release formulation intended for oral administration to humans may contain 20 to 2000 μmol (approximately 10 to 1000 mg) of active material compounded with an appropriate and convenient amount of

15 carrier material which may vary from about 5 to about 95% of the total compositions. It is preferred that the pharmaceutical composition be prepared which provides easily measurable amounts for administration. For example, an aqueous solution intended for intravenous infusion should contain from about 0.05 to about 50 μmol (approximately 0.025 to 25 mg) of the active ingredient per milliliter of solution in order that infusion

20 of a suitable volume at a rate of about 30 mL/hr can occur.

As noted above, formulations of the present invention suitable for oral administration may be presented as discrete units such as capsules, cachets or tablets each containing a predetermined amount of the active ingredient; as a powder or granules; as a solution or a suspension in an aqueous or non-aqueous liquid; or as an oil-in-water liquid emulsion or a water-in-oil liquid emulsion. The active ingredient may also be administered as a bolus, electuary or paste.

A tablet may be made by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a

suitable machine the active ingredient in a free flowing form such as a powder or granules, optionally mixed with a binder (e.g., povidone, gelatin, hydroxypropylmethyl cellulose), lubricant, inert diluent, preservative, disintegrant (e.g., sodium starch glycolate, cross-linked povidone, cross-linked sodium carboxymethyl cellulose) surface

5 active or dispersing agent. Molded tablets may be made by molding in a suitable machine a mixture of the powdered compound moistened with an inert liquid diluent. The tablets may optionally be coated or scored and may be formulated so as to provide slow or controlled release of the active ingredient therein using, for example, hydroxypropyl methylcellulose in varying proportions to provide the desired release
10 profile. Tablets may optionally be provided with an enteric coating, to provide release in parts of the gut other than the stomach. This is particularly advantageous with the compounds of formula 1 when such compounds are susceptible to acid hydrolysis.

Formulations suitable for topical administration in the mouth include lozenges comprising the active ingredient in a flavored base, usually sucrose and acacia or tragacanth; pastilles comprising the active ingredient in an inert base such as gelatin and glycerin, or sucrose and acacia; and mouthwashes comprising the active ingredient in a suitable liquid carrier.

Formulations for rectal administration may be presented as a suppository with a suitable base comprising for example cocoa butter or a salicylate.

20 Formulations suitable for vaginal administration may be presented as pessaries, tampons, creams, gels, pastes, foams or spray formulations containing in addition to the active ingredient such carriers as are known in the art to be appropriate.

Formulations suitable for parenteral administration include aqueous and non-aqueous isotonic sterile injection solutions which may contain antioxidants, buffers,
25 bacteriostats and solutes which render the formulation isotonic with the blood of the intended recipient; and aqueous and non-aqueous sterile suspensions which may include suspending agents and thickening agents. The formulations may be presented in unit-dose or multi-dose sealed containers, for example, ampoules and vials, and may be

stored in a freeze-dried (lyophilized) condition requiring only the addition of the sterile liquid carrier, for example water for injections, immediately prior to use. Injection solutions and suspensions may be prepared from sterile powders, granules and tablets of the kind previously described.

5 Preferred unit dosage formulations are those containing a daily dose or unit, daily sub-dose, or an appropriate fraction thereof, of a fructose 1,6-bisphosphatase inhibitor compound.

It will be understood, however, that the specific dose level for any particular patient will depend on a variety of factors including the activity of the specific

10 compound employed; the age, body weight, general health, sex and diet of the individual being treated; the time and route of administration; the rate of excretion; other drugs which have previously been administered; and the severity of the particular disease undergoing therapy, as is well understood by those skilled in the art.

Utility

15 FBPase inhibitors at the AMP site may be used to treat diabetes mellitus, lower blood glucose levels, and inhibit gluconeogenesis.

FBPase inhibitors at the AMP site may also be used to treat excess glycogen storage diseases. Excessive hepatic glycogen stores are found in patients with some glycogen storage diseases. Since the indirect pathway contributes significantly to 20 glycogen synthesis (Shulman, G.I. *Phys. Rev.* 1992. 72, 1019-1035), inhibition of the indirect pathway (gluconeogenesis flux) is expected to decrease glycogen overproduction.

FBPase inhibitors at the AMP site may also be used to treat or prevent diseases associated with increased insulin levels.

25 Increased insulin levels are associated with an increased risk of cardiovascular complications and atherosclerosis (Folsom, et al., *Stroke*, 1994, 25, 66-73; Howard, G. et al., *Circulation* 1996, 93, 1809-1817). FBPase inhibitors are expected to decrease postprandial glucose levels by enhancing hepatic glucose uptake. This effect is

postulated to occur in individuals that are non-diabetic (or pre-diabetic, i.e. without elevated HGO or fasting blood glucose levels). Increased hepatic glucose uptake will decrease insulin secretion and thereby decrease the risk of diseases or complications that arise from elevated insulin levels.

5 The compounds of this invention and their preparation can be understood further by the examples which illustrate some of the processes by which these compounds are prepared. These examples should not, however, be construed as specifically limiting the invention and variations of the invention, now known or later developed, are considered to fall within the scope of the present invention as hereinafter claimed.

10

EXAMPLES

Example 1

Preparation of 5-diethylphosphono-2-furaldehyde (1).

Step A. A solution of 2-furaldehyde diethyl acetal (1 mmol) in THF was treated with nBuLi (1 mmol) at -78 °C. After 1 h, diethyl chlorophosphate (1.2 mmol) was added and the reaction was stirred for 40 min. Extraction and evaporation gave a brown oil.

Step B. The resulting brown oil was treated with 80 % acetic acid at 90 °C for 4 h. Extraction and chromatography gave compound 1 as a clear yellow oil.

Alternatively this aldehyde can be prepared from furan as described below.

Step C. A solution of furan (1 mmol) in diethyl ether was treated with TMEDA (N,N,N',N'-tetramethylethylenediamine) (1 mmol) and nBuLi (2 mmol) at -78 °C. The solution was stirred for 0.5 h. at -78 °C and diethyl chlorophosphate was added and stirred for another 1 h. Extraction and distillation produced diethyl 2-furanphosphonate as a clear oil.

Step D. A solution of diethyl 2-furanphosphonate (1 mmol) in THF (tetrahydrofuran) was treated with LDA (1.12 mmol, lithium N,N-diisopropylamide) at

-78 °C for 20 min. Methyl formate (1.5 mmol) was added and the reaction was stirred for 1 h. Extraction and chromatography gave compound 1 as a clear yellow oil.

Preferably this aldehyde can be prepared from 2-furaldehyde as described below.

5 Step E. A solution of 2-furaldehyde (1 mmol) and N,N'-dimethylethylene diamine (1 mmol) in toluene was refluxed with a Dean-Stark trap to collect the resulting water. After 2 h the solvent was removed in vacuo and the residue was distilled to give furan-2-(N,N'-dimethylimidazolidine) as a clear colorless oil, bp 59-61 °C (3 mm Hg).

Step F. A solution of furan-2-(N,N'-dimethylimidazolidine) (1 mmol) and

10 TMEDA (1 mmol) in THF was treated with nBuLi (1.3 mmol) at -40 to -48 °C. The reaction was stirred at 0 °C for 1.5 h and then cooled to -55 °C and treated with a solution of diethylchlorophosphate (1.1 mmol) in THF. After stirring at 25 °C for 12 h the reaction mixture was evaporated and subjected to extraction to give 5-diethylphosphono-furan-2-(N,N'-dimethylimidazolidine) as a brown oil.

15 Step G. A solution of 5-diethylphosphonofuran-2-(N,N'-dimethylimidazolidine) (1 mmol) in water was treated with concentrated sulfuric acid until pH = 1. Extraction and chromatography gave compound 1 as a clear yellow oil.

Example 2.

Preparation of N⁹-substituted-8-(2-(5-phosphono)furanyl)adenines.

20 The preparation of N⁹-(2-phenethyl)-8-(2-(5-phosphono)furanyl)adenine is given as an example:

Step A. A solution of 5-amino-4,6-dichloropyrimidine (1 mmol) in nBuOH was treated with Et₃N (1.2 mmol) and phenethylamine (1.05 mmol) at 80 °C. After 12 h, the cooled reaction mixture was evaporated under vacuum and the residue was

25 chromatographed to give 6-chloro-5-amino-4-(phenethylamino)-pyrimidine as a yellow solid. mp 156 - 157 °C; TLC: R_f = 0.41, 50 % EtOAc-hexane.

Step B. The 6-chloro-5-amino-4-(phenethylamino)pyrimidine (1 mmol) in DMSO was treated with 2-furaldehyde (1.5 mmol) and FeCl₃-silica (2.0 mmol) at

80 °C. After 12 h, the cooled reaction mixture was filtered and the filtrate was evaporated under vacuum. Chromatography afforded 6-chloro-N⁹-(2-phenethyl)-8-(2-furanyl)purine as a yellow solid. TLC: R_f= 0.62, 50 % EtOAc-hexane. Anal. calcd. for C₁₇H₁₃N₄OCl: C: 62.87; H: 4.03; N: 17.25. Found: C: 62.66; H: 3.96; N: 17.07.

5 **Step C.** The 6-chloro-N⁹-(2-phenethyl)-8-(2-furanyl)purine (1 mmol) in THF was treated with LDA (1.5 mmol) at -78 °C. After 1 h, diethyl chlorophosphosphate (5 mmol) was added and the reaction was stirred at -78 °C for 2 h and then quenched with saturated NH₄Cl. Extraction and chromatography gave 6-chloro-N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)-furanyl)purine as a yellow solid. TLC: R_f= 0.34, 100 % EtOAc.

10 Alternatively this type of compound can be prepared as follows:

Step D. A solution of 6-chloro-5-amino-4-(2-phenethylamino)pyrimidine (1 mmol) in DMSO was treated with 5-diethylphosphono-2-furaldehyde (1, 1.5 mmol), and FeCl₃-silica (2.0 mmol) at 80 °C. After 12 h., the cooled reaction mixture was filtered and the filtrate was evaporated under vacuum. Chromatography afforded 6-chloro-N⁹-(2-phenethyl)-8-(2-(5-diethyl-phosphono)furanyl)purine as a yellow solid. TLC: R_f= 0.34, 100 % EtOAc.

15 **Step E.** 6-Chloro-N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)furanyl)-purine (1 mmol) in THF-DMSO was treated with liquid ammonia (2 mL) in a steel bomb. After 12 h, the reaction was evaporated under vacuum and the residue was purified 20 through chromatography to give N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)furanyl)adenine as a yellow solid. TLC: R_f= 0.12, 5 % MeOH - CH₂Cl₂.

25 **Step F.** A solution of N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)furanyl)-adenine (1 mmol) in acetonitrile was treated with bromotrimethylsilane (10 mmol). After 12 h, the reaction was evaporated under vacuum and the residue was treated with a mixture of water and acetonitrile. The solid was collected through filtration to give N⁹-(2-phenethyl)-8-(2-(5-phosphono)furanyl)adenine (**2.1**). mp 242-244° C; Anal.

calcd. for C₁₇H₁₆N₅O₄P + 1.37H₂O: C: 50.16; H: 4.64; N: 17.21. Found: C: 48.95; H: 4.59; N: 16.80.

The following compounds were prepared according to above procedures:

2.2: N⁹-(2-cyclohexylethyl)-8-(2-(5-phosphono)furanyl)adenine. mp 194-195 °C ;

5 Anal. calcd. for C₁₇H₂₂N₅O₄P + 1 H₂O: C: 49.90; H: 5.90; N: 17.10. Found: C: 50.20; H: 5.70; N: 17.10.

2.3: N⁹-(2-naphthylmethyl)-8-(2-(5-phosphono)furanyl)adenine. mp 255-256 °C ;

Anal. calcd. for C₂₀H₁₆N₅O₄P + 1 H₂O: C: 54.70; H: 4.10; N: 15.90. Found: C: 54.30; H: 4.20; N: 15.90.

10 **2.4:** N⁹-(1-(2,2-diphenyl)ethyl)-8-(2-(5-phosphono)furanyl)adenine. mp 220-221 °C ;
Anal. calcd. for C₂₃H₂₀N₅O₄P + 0.25 H₂O: C: 59.29; H: 4.43; N: 15.03. Found:
C: 59.35; H: 4.25; N: 14.83.

2.5: N⁹-ethyl-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₁H₁₂N₅O₄P + 1 H₂O: C: 40.38; H: 4.31; N: 21.40. Found: C: 40.45; H: 4.18; N: 21.44.

15 **2.6:** N⁹-isobutyl-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₃H₁₆N₅O₄P: C: 46.30; H: 4.78; N: 20.76. Found: C: 46.00; H: 4.61; N: 20.49.

2.7: N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₄H₁₈N₅O₄P: C: 47.87; H: 5.16; N: 19.94. Found: C: 47.59; H: 4.92; N: 19.53.

20 **2.8:** N⁹-adamentanemethyl-8-(2-(5-phosphono)furanyl)adenine. mp > 250 °C ; Anal. calcd. for C₂₀H₂₄N₅O₄P + 0.5 H₂O + 0.25 MeOH: C: 54.48; H: 5.87; N: 15.69. Found:
C: 54.62; H: 5.52; N: 15.36.

2.9: N⁹-cyclopropyl-8-(2-(5-phosphono)furanyl)adenine. mp > 250 °C ; MS (M + H) calcd for C₁₂H₁₃N₅O₄P: 322, found: 322.

25 **2.10:** N⁹-cyclopentyl-8-(2-(5-phosphono)furanyl)adenine. mp 220 °C (decomp); Anal. calcd. for C₁₄H₁₆N₅O₄P + 1 H₂O: C: 45.78; H: 4.94; N: 19.07. Found: C: 45.40; H: 4.79;
N: 18.73.

2.11: N⁹-((2-ethoxy)phenyl)methyl-8-(2-(5-phosphono)furanyl)-adenine. mp > 230 °C ; Anal. calcd. for C₁₈H₁₈N₅O₅P + 2 H₂O: C: 47.90; H: 4.91; N: 15.52. Found: C: 48.03; H: 4.53; N: 15.25.

2.12: N⁹-(1-(3-N,N-dimethylamino-2,2-dimethyl)propyl)-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₆H₂₃N₆O₄P + 3 H₂O + 0.5 HOAc + 0.75 Na: C: 41.19; H: 6.30; N: 16.95. Found: C: 41.35; H: 6.04; N: 16.57.

2.13: N⁹-(1-(3-hydroxyl-2,2-dimethyl)propyl)-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₄H₁₈N₅O₅P + 0.25 H₂O: C: 45.23; H: 5.02; N: 18.83. Found: C: 45.40; H: 5.02; N: 18.44.

2.14: N⁹-(1-(3-chloro-2,2-dimethyl)propyl)-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₄H₁₇N₅O₄PCl + 0.125 CHCl₃ + 0.06 AcOEt: C: 42.50; H: 4.37; N: 17.25. Found: C: 42.62; H: 3.99; N: 16.87.

2.15: N⁹-(1-(3,3-dimethylbutyl)-8-(2-(5-phosphono)furanyl)adenine. mp 230 °C ; Anal. calcd. for C₁₅H₂₀N₅O₄P + 1.25H₂O + 0.13 AcOEt: C: 46.68; H: 5.94; N: 17.56. Found: C: 46.67; H: 5.78; N: 17.35.

2.16: N⁹-(1,5,5-trimethyl-3-cyclohexenyl)methyl-8-(2-(5-phosphono)furanyl)adenine. mp > 230 °C ; Anal. calcd. for C₁₉H₂₄N₅O₄P + 0.5 H₂O + 0.13 AcOEt: C: 53.54; H: 5.99; N: 16.01. Found: C: 53.67; H: 5.69; N: 15.75.

2.17: N⁹-(1-(1,2,2-trimethyl)propyl)-8-(2-(5-phosphono)furanyl)adenine. mp > 250 °C ; Anal. calcd. for C₁₅H₂₀N₅O₄P + 0.67 H₂O + 0.13AcO Et: C: 47.74; H: 5.70; N: 18.56. Found: C: 47.99; H: 5.39; N: 18.49.

2.18: 6-Amino-9-(3-(1-imidazolyl)propyl)-8-(2-(5-phosphono)furanyl)purine. mp 182-186 °C; Mass calcd. for C₁₅H₁₆N₇O₄P: 389. Found: M + H⁺ = 390.

Examples 3.

25 Preparation of N⁹-substituted-8-(2-phosphonoethylamino)adenines.

Step A. Adenine (1 mmol) in DMF was treated with sodium hydride (1.2 mmol) followed by benzyl bromide (1.2 mmol) at room temperature under nitrogen. The

resulting mixture was warmed at 100 °C for 2 h. The cooled reaction mixture was evaporated to dryness. Extraction and chromatography afforded N⁹-benzyladenine.

Step B. A solution of N⁹-benzyladenine (1 mmol) in acetic acid buffer (pH = 4) was treated with bromine (1 mmol) at room temperature for 12 h. The reaction was

5 quenched with 10 % sodium sulfite solution and extracted with dichloromethane. The combined extracts were dried (Na₂SO₄) and evaporated to dryness. Chromatography afforded N⁹-benzyl-8-bromoadenine.

Step C. A mixture of N⁹-benzyl-8-bromoadenine (1 mmol), aminoethylphosphonate (2 mmol), and sodium hydroxide (2 mmol) in ethanol-water in 10 a sealed tube was warmed at 110 °C under nitrogen. After 24 h the cooled reaction mixture was purified through preparative HPLC to give N⁹-benzyl-8-(2-phosphonoethylamino)adenine (3.1). Exact mass calculated for C₁₄H₁₇N₆O₃P + H⁺: 349.1178. Found: 349.1180.

The following compounds were prepared according to this procedure:

15 **3.2:** N⁹-phenethyl-8-(2-phosphonoethylamino)adenine. mp 159-160 °C ; Anal. calcd. for C₁₅H₁₉N₆O₃P + 1.25 H₂O: C: 46.81; H: 5.63; N: 21.84. Found: C: 47.05; H: 5.63; N: 21.48.

3.3: N⁹-(2-naphthylmethyl)-8-(2-phosphonoethylamino)adenine. mp 189-190 °C ; Anal. calcd. for C₁₈H₁₉N₆O₃P + 1.5 H₂O: C: 50.82; H: 5.21; N: 19.76. Found: C: 50.71;

20 H: 5.25; N: 19.54.

3.4: N⁹-cyclohexylethyl-8-(2-phosphonoethylamino)adenine. mp > 250 °C ; Anal. calcd. for C₁₅H₂₅N₆O₃P + 0.33 H₂O: C: 48.12; H: 6.91; N: 22.44. Found: C: 48.12; H: 6.78; N: 22.15.

Example 4.

25 **Preparation of 8-(2-phosphonoethylamino)adenosines.**

A mixture of 8-bromoadenosine (1 mmol), aminoethylphosphonate (2 mmol), and sodium hydroxide (2 mmol) in ethanol-water in a sealed tube was warmed at 110 °C under nitrogen. After 24 h the cooled reaction mixture was purified through

preparative HPLC to give 8-(2-phosphonoethylamino)-adenosine (**4.1**). mp 175 °C ;
Anal. calcd. for C₁₂H₁₉N₆O₇P + 0.5 H₂O: C: 36.10; H: 5.05; N: 21.05; P: 7.76. Found:
C: 36.08; H: 4.83; N: 20.36; P: 7.86.

The following compound was prepared in this manner:

5 **4.2:** 8-(2-Phosphonoethylamino)-5-deoxyadenosine as a white solid. mp 220 °C ;
Anal. calcd. for C₁₂H₁₉N₆O₆P + 1.5 H₂O: C: 35.92; H: 5.53; N: 20.94. Found: C: 36.15;
H: 5.12; N: 20.53.

Examples 5.

Preparation of N⁹-alkyl-8-(phosphonomethoxymethyl)adenines.

10 **Step A.** A mixture of N⁹-phenethyl-8-bromoadenine (1 mmol), tetrakis (triphenylphosphine)palladium (0.05 mmol), and triethylamine (5 mmol) in DMF in a sealed tube was warmed at 110 °C under 50 psi of carbon monoxide. After 24 h the cooled reaction mixture was evaporated and purified through chromatography to give N⁹-phenethyl-8-methoxycarbonyladanine as a yellow solid. TLC: R_f= 0.12, 5 %

15 MeOH-CH₂Cl₂.

Step B. A solution of N⁹-phenethyl-8-methoxycarbonyladanine (1 mmol) in tetrahydrofuran was treated with lithium aluminum hydride (1 mmol) at 0 °C for 1 h. Extraction and chromatography gave N⁹-phenethyl-8-hydroxymethyl-adenine as a white solid. TLC: R_f= 0.31, 10 % MeOH-CH₂Cl₂.

20 **Step C.** A solution of N⁹-phenethyl-8-hydroxymethyladaine (1 mmol) in methylene chloride was treated with phosphorus tribromide (1 mmol) at 25 °C for 1 h. Extraction and chromatography gave N⁹-phenethyl-8-bromomethyl-adenine as a white solid. TLC: R_f = 0.31, 10 % MeOH-CH₂Cl₂.

Step D. A solution of N⁹-phenethyl-8-bromomethyladaine (1 mmol) in DMF was treated with a solution of diethyl hydroxymethylphosphonate sodium salt (1 mmol) in DMF at 25 °C for 1 h. Extraction and chromatography gave N⁹-phenethyl-8-diethylphosphonomethoxymethyladaine as a white solid. TLC: R_f = 0.31, 10 % MeOH-CH₂Cl₂.

^{N⁹}-phenethyl-8-diethylphosphonomethoxymethyladenine was subjected to Step F in Example 2 to give ^{N⁹}-(2-phenethyl)-8-(phosphonomethoxymethyl)-adenine (**5.1**) as a white solid. mp > 250 °C ; Anal. calcd. for C₁₉H₂₂N₅O₄P + 0.75 H₂O: C: 56.93; H: 5.91; N: 10.48. Found: C: 56.97; H: 5.63; N: 10.28.

5 The following compounds were prepared according to this procedure:

5.2: ^{N⁹}-(2-cyclohexylethyl)-8-(phosphonomethoxymethyl)adenine. mp > 250 °C ; Anal. calcd. for C₁₅H₂₄N₅O₄P + 1 H₂O: C: 46.51; H: 6.76; N: 18.08. Found: C: 46.47; H: 6.71; N: 17.91.

5.3: ^{N⁹}-(1-nanonyl)-8-(phosphonomethoxymethyl)adenine. mp 195-210 °C ; Anal. calcd. for C₁₆H₂₈N₅O₄P + 1 H₂O: C: 47.64; H: 7.50; N: 17.36. Found: C: 47.33; H: 7.34; N: 16.99.

5.4: ^{N⁹}-(3-cyclohexylpropyl)-8-(phosphonomethoxymethyl)adenine. mp 230-250 °C; Anal. calcd. for C₁₉H₂₂N₅O₄P + 0.9 H₂O + 0.3 HBr: C: 45.34; H: 6.68; N: 16.52. Found: C: 45.74; H: 6.39; N: 16.18.

15 Alternatively this type of compound can also be prepared according to the following procedure:

Step E. A solution of 6-chloro-5-amino-4-(neopentylamino)pyrimidine (1 mmol) in diethyl ether was treated with pyridine (3 mmol), and acetoxyacetyl chloride (1.2 mmol) at 25 °C for 12 h. Extraction and chromatography afforded 6-chloro-5-acetoxyacetyl-amino-4-neopentylaminopyrimidine as a yellow solid. TLC: R_f = 0.18, 20 30 % EtOAc-hexane.

Step F. A solution of 6-chloro-5-acetoxyacetylamino-4-neopentylaminopyrimidine (1 mmol) in phosphorus oxychloride was heated at reflux for 6 h. The cooled reaction mixture was evaporated to dryness and the residue was dissolved in pyridine and stirred at 25 °C for 20 h. Evaporation and chromatography afforded 6-chloro-8-acetoxymethyl-^{N⁹}-neopentylpurine as a yellow solid. TLC: R_f = 0.51, 50 % EtOAc-hexane.

Step G. A solution of 6-chloro-8-acetoxymethyl-N⁹-neopentylpurine (1 mmol) in THF-water was treated with aqueous sodium hydroxide (1.5 mmol) at 0 °C for 0.5 h. Extraction and chromatography afforded 6-chloro-8-hydroxymethyl-N⁹-neopentylpurine as a yellow gel. TLC: R_f = 0.38, 33 % EtOAc-hexane.

5 Step H. A solution of 6-chloro-8-hydroxymethyl-N⁹-neopentylpurine (1 mmol) in methylene chloride was treated with phosphorus tribromide (1 mmol) at 25 °C for 6 h. Extraction and chromatography afforded 6-chloro-8-bromomethyl-N⁹-neopentylpurine as a white solid. TLC: R_f = 0.64, 25 % EtOAc-hexane.

10 Step I. A solution of 6-chloro-8-bromomethyl-N⁹-neopentylpurine (1 mmol) in DMF was treated with a solution of sodium diethylphosphono-methoxide (1 mmol) at 25 °C for 6 h. Extraction and chromatography afforded 6-chloro-8-diethylphosphonomethoxymethyl-N⁹-neopentylpurine as a white solid. TLC: R_f = 0.31, 50 % EtOAc-hexane.

15 Step J. A solution of 6-chloro-8-diethylphosphonomethoxymethyl-N⁹-neopentylpurine (1 mmol) in THF-DMSO was treated with liquid ammonia (10 mmol) at 25 °C for 6 h. Extraction and chromatography afforded 8-diethylphosphonomethoxymethyl-N⁹-neopentyladenine as a white solid. TLC: R_f = 0.44, 25 % MeOH-EtOAc.

20 8-Diethylphosphonomethoxymethyl-N⁹-neopentyladenine was subjected to Step F in Example 2 to give N⁹-neopentyl-8-(phosphonomethoxymethyl)-adenine (**5.5**) as a white solid. mp > 250 °C ; Anal. calcd. for C₁₂H₂₀N₅O₄P + 1.5 H₂O: C: 40.45; H: 6.51; N: 19.65. Found: C: 40.68; H: 6.35; N: 19.40.

Examples 6.

Preparation of N⁹-substituted-8-(1-(3-phosphono)propyl)adenines.

25 Step A. A mixture of diethyl propargylphosphonate (1 mmol, prepared according to *J. Org. Chem.*, 1993, 58(24), 6531.), tributyltin hydride (1.05 mmol), and AIBN (0.005 mmol) was heated at 60 °C for 18 h. The cooled reaction mixture was purified

through chromatography to give dimethyl (1-tributylstannylyl)allyl-3-phosphonate as a yellow oil.

Step B. A solution of N⁹-(2-cyclohexylethyl)-8-bromo adenine (1 mmol), tetrakis(triphenylphosphine)palladium (0.1 mmol), and dimethyl (1-

5 tributylstannylyl)allyl-3-phosphonate (5 mmol) in DMF was warmed at 90 °C under nitrogen. After 2 h the cooled reaction mixture was evaporated and purified through chromatography to give N⁹-(2-cyclohexylethyl)-8-(3-dimethylphosphonopropene-1-yl)adenine as a yellow solid. TLC: R_f = 0.48, 10 % MeOH - CH₂Cl₂.

Step C. A solution of N⁹-(2-cyclohexylethyl)-8-(3-dimethylphosphono-propene-

10 1-yl)adenine in methanol-acetic acid was stirred at room temperature under 50 psi of H₂ for 12 h. Filtration and chromatography afforded N⁹-(2-cyclohexylethyl)-8-(1-(3-dimethylphosphono)propyl)adenine as a yellow solid. TLC: R_f = 0.26, 10 % MeOH - CH₂Cl₂.

N⁹-(2-cyclohexylethyl)-8-(1-(3-dimethylphosphono)propyl)adenine was subjected to Step F in Example 2 to give N⁹-(2-cyclohexylethyl)-8-(1-(3-phosphono)propyl)adenine (**6.1**) as a white solid: mp 122-125 °C ; Anal. calcd. for C₁₆H₂₆N₅O₃P + 0.25 AcOH: C: 51.83; H: 7.12; N: 18.31. Found: C: 51.87; H: 6.96; N: 17.96.

6.2: N⁹-(2-phenethyl)-8-(1-(3-phosphono)propyl)adenine was also prepared in this manner as a solid. mp > 250 °C Anal. calcd. for C₁₆H₂₀N₅O₃P + 0.5 H₂O: C: 51.89; H: 5.71; N: 18.91. Found: C: 51.81; H: 5.49; N: 18.66.

Examples 7.

Preparation of N⁹-(2-phenethyl)-8-(2-(5-phosphono)thienyl)adenine.

Step A. A solution of 2-thienyllithium in THF (1 mmol) was added to a solution

25 of diethyl chlorophosphate (1 mmol) at -78 °C under nitrogen. After 2 h the reaction was warmed to room temperature and quenched with brine. Extraction and chromatography afforded 2-diethylphosphonothiophene as a yellow oil. TLC: R_f = 0.37, 50 % EtOAc - hexane.

Step B. A solution of 2-diethylphosphonothiophene (1 mmol) in THF was treated with nBuLi at -78 °C for 1 h. Tributyltin chloride was added and stirred at -78 °C for 2 h and the reaction was quenched with water and warmed to room temperature. Extraction and chromatography afforded diethyl 2-(5-tributylstannylyl)thienylphosphonate as a yellow oil. TLC: $R_f = 0.65$, 50 % EtOAc - hexane.

Step C. A mixture of N⁹-phenethyl-8-bromo adenine (1 mmol), tetrakis (triphenylphosphine)palladium (0.1 mmol), and diethyl 2-(5-tributylstannylyl)thienylphosphonate (5 mmol) in DMF was warmed at 80 °C under nitrogen. After 21 h the cooled reaction mixture was evaporated to dryness. The dark oil was triturated with hexane and the residue was dissolved in CH₂Cl₂ and filtered. The filtrate was evaporated to give N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)-thienyl)adenine as a yellow solid. TLC: $R_f = 0.50$, 10 % MeOH - CH₂Cl₂.

N⁹-(2-phenethyl)-8-(2-(5-diethylphosphono)thienyl)adenine was subjected to Step F in Example 2 to give N⁹-(2-phenethyl)-8-(2-(5-phosphono)-thienyl)adenine (7.1) as a white solid. mp > 250 °C ; Anal. calcd. for C₁₇H₁₆N₅O₃SP + 0.5H₂O: C: 49.76; H: 4.17; N: 17.07. Found: C: 50.07; H: 4.02; N: 17.45.

N⁹-(2-phenethyl)-8-(2-(5-phosphono)thienyl)adenine can also be made via a cyclization reaction between 5-diethylphosphono-2-thiophene-carboxaldehyde (prepared from 2-thienyllithium as described in Steps C and D of Example 1) as described in Example 2.

Example 8.

Preparation of N⁹-(2-cyclohexylethyl)-8-(phosphonomethylthio)-adenine.

Step A. A mixture of N⁹-(2-cyclohexylethyl)-8-bromo adenine (1 mmol), and K₂S (4 mmol) in ethanol was warmed at 110 °C for 7 h, and at 85 °C for 12 h. The cooled reaction mixture was filtered, evaporated and purified through chromatography to give N⁹-(2-cyclohexylethyl)-8-thiohydroxyadenine as a yellow solid. TLC: $R_f = 0.26$, 5 % MeOH - CH₂Cl₂.

Step B. A mixture of N⁹-(2-cyclohexylethyl)-8-thiohydroxyadenine (1 mmol), K₂CO₃ (4 mmol), and diethyl chloromethylphosphonate (3 mmol) in DMF was stirred at room temperature for 48 h. Extraction and chromatography gave N⁹-(2-cyclohexylethyl)-8-diethylphosphono-methylthioadenine. TLC: R_f = 0.35, 10 % MeOH - EtOAc.

N⁹-(2-Cyclohexylethyl)-8-diethylphosphonomethylthioadenine was subjected to Step F in Example 2 to give N⁹-(2-cyclohexylethyl)-8-(phosphonomethylthio)adenine (8.1) as a white solid. mp 240 - 243 °C ; Anal. Calcd. for C₁₄H₂₂N₅O₃SP + 1.25H₂O: C: 42.69; H: 5.95; N: 17.54. Found: C: 42.62; H: 6.03; N: 17.80.

10 Example 9.

Preparation of 6-chloro-9-phenethyl-8-(2-(5-phosphono)furanyl)purine.

6-Chloro-N⁹-phenethyl-8-(2-(5-diehtylphosphono)furanyl)purine (Step C in Example 2) was subjected to procedure of Step F in Example 2 to give compound 9.1 as a yellow solid. mp >200 °C ; Anal. calcd. for C₁₇H₁₄N₄O₄PCl + 2 H₂O + 0.28 HBr:

15 C: 44.06; H: 3.98; N: 12.09. Found: C: 43.86; H: 3.59; N: 12.02.

Example 10.

Preparation of N⁶,N⁹-substituted-8-(2-(5-phosphono)furanyl)adenines.

A solution of 6-chloro-N⁹-substituted-8-(2-(5-diethylphosphono)furanyl)-purine (1 mmol) in DMSO was treated with alkylamine at 100 °C for 12 h. Evaporation and chromatography gave N⁶,N⁹-substituted-8-(2-(5-diethyl-phosphono)furanyl)adenines.

The title compounds were obtained by subjecting N⁶,N⁹-substituted-8-(2-(5-diethylphosphono)furanyl)adenines to the procedure of Step F in Example 2.

The following compounds were prepared in this manner:

10.1: 6-Dimethylamino-N⁹-phenethyl-8-(2-(5-phosphono)furanyl)purine as a white solid. mp >200 °C ; Anal. calcd. for C₁₉H₂₀N₅O₄P: C: 55.2; H: 4.8; N: 16.9. Found: C: 54.9; H: 4.9; N: 16.6.

10.2: 6-Methylamino-N⁹-phenethyl-8-(2-(5-phosphono)furanyl)purine as a white solid.
mp 242 °C ; Anal. calcd. for C₁₈H₁₈N₅O₄P + 1 H₂O: C: 51.8; H: 4.8; N: 16.8. Found:
C: 51.7; H: 4.8; N: 16.7.

Example 11.

5 Preparation of 2-methylthio-6-amino-N⁹-isobutyl-8-(2-(5-phosphono)furanyl)purine and 2-methylsulfonyl-6-amino-N⁹-isobutyl-8-(2-(5-phosphono)furanyl)purine.
Step A: 2-Methylthio-4,5,6-triaminopyrimidine and 5-diethylphosphono-2-furaldehyde was subjected to the procedures of Step D in Example 2 to give 6-amino-2-methylthio-8-(2-(5-diethylphosphono)furanyl)purine as a yellow solid. TLC: R_f = 0.27,
10 80 % EtOAc - hexane.

Step B: 6-Amino-2-methylthio-8-(2-(5-diethylphosphono)furanyl)purine was alkylated with isobutyl bromide following the procedures of Step A in Example 3 to give 6-amino-N⁹-isobutyl-2-methylthio-8-(2-(5-diethylphosphono)-furanyl)purine as a yellow solid. TLC: R_f = 0.27, 80 % EtOAc - hexane.

15 Step C: 6-Amino-N⁹-isobutyl-2-methylthio-8-(2-(5-diethyl-phosphono)- furanyl)purine was subjected to Step F in Example 2 to give 6-amino-N⁹-isobutyl-2-methylthio-8-(2-(5-phosphono)-furanyl)purine (**11.1**) as a white solid. mp 220 °C ;
Anal. calcd. for C₁₄H₁₈N₅O₄PS + 0.25 HBr + 0.25 EtOAc: C: 42.33; H: 4.8; N: 16.45.
Found: C: 42.42; H: 4.53; N: 16.39.

20 Step D: A solution of 6-amino-N⁹-isobutyl-2-methylthio-8-(2-(5-diethyl-phosphono)furanyl)purine (1 mmol) in 50 mL of methanol was cooled to 0 °C and treated with an acetone solution of Oxone (1.6 mmol). After stirring for 3 h at 25 °C the reaction was extracted and then chromatographed to give 6-amino-N⁹-isobutyl-2-methylsulfonyl-8-(2-(5-diethylphosphono)furanyl)purine as a white solid. TLC: R_f = 0.24, 100 % EtOAc.

Step E: 6-Amino-N⁹-isobutyl-2-methylsulfonyl-8-(2-(5-diethylphosphono)- furanyl)purine was subjected to Step F in Example 2 to give 6-amino-N⁹-isobutyl-2-methylsulfonyl-8-(2-(5-phosphono)furanyl)purine (**11.2**) as a white solid. mp 240 °C

(decomp); Anal. calcd. for $C_{14}H_{18}N_5O_6PS + 0.5 H_2O$: C: 39.62; H: 4.51; N: 16.5.

Found: C: 39.77; H: 4.44; N: 16.12.

Example 12.

Preparation of 6-amino-N⁹-neopentyl-8-(2-(3,4-dichloro-5-phosphono)furanyl)purine.

5 Step A: A solution of 3,4-dichloro-2-furoic acid (1 mmol) in diethyl ether was treated with LDA (3 mmol) at -78 °C for 30 min and then treated with diethyl chlorophosphate (3.5 mmol) at -78 °C for 1 h. The reaction was quenched and extracted to give 5-diethylphosphono-3,4-dichloro-2-furoic acid as a yellow foam.

10 Step B: A solution of 5-diethylphosphono-3,4-dichloro-2-furoic acid (1 mmol) in methylene chloride was treated with oxalyl chloride and DMF at 25 °C for 1 h. The reaction mixture was evaporated and the residue was dissolved in diethyl ether and treated with a solution of 4-chloro-5-amino-6-neopentyl-aminopyrimidine (1 mmol) and pyridine (3 mmol) in diethyl ether at 25 °C for 16 h. Extraction and chromatography gave 4-chloro-5-(2-(3,4-dichloro-5-diethylphosphono)furoyl)amino-6-neopentylaminopyrimidine as a yellow solid. TLC: $R_f = 0.4$, 50 % EtOAc - hexane.

15 Step C: A solution of 4-chloro-5-(2-(3,4-dichloro-5-diethylphosphono)-furoyl)amino-6-neopentylaminopyrimidine (1 mmol) in dichloromethane was treated with silicone tetrachloride (2.5 mmol) and triethylamine (2.5 mmol) at 45 °C for 18 h. The cooled reaction mixture was subjected to extraction and chromatography to give 6-chloro-N⁹-neopentyl-8-(2-(3,4-dichloro-5-diethyl-phosphono)furanyl)purine as a yellow solid. TLC: $R_f = 0.28$, 50 % EtOAc - hexane.

20 Step D: 6-Chloro-N⁹-neopentyl-8-(2-(3,4-dichloro-5-diethylphosphono)-furanyl)purine was subjected to Steps E and F in Example 2 to give 6-amino-N⁹-neopentyl-8-(2-(3,4-dichloro-5-phosphono)furanyl)purine (**12.1**) as a white solid. mp > 250 °C ; Anal. calcd. for $C_{14}H_{16}N_5O_4PCl_2 + 0.5 H_2O + 0.15 EtOAc$: C: 39.64; H: 4.15; N: 15.83. Found: C: 39.82; H: 3.88; N: 15.46.

Example 13.Preparation of hydroxyethyldisulfidylethylphosphonate diester.

A suspension of 8-(2-(5-phosphono)furanyl)-N⁹-phenethyladenine (1 mmol) in thionyl chloride (5 mL) was warmed at reflux for 4 h. The cooled reaction mixture was evaporated to dryness and the resulting yellow residue was treated with a solution of 2-hydroxyethyl disulfide (4 mmol), pyridine (2.5 mmol) in methylene chloride. After stirring at 25 °C for 4 h the reaction was subjected to extraction and chromatography to give two compounds:

13.1: N⁹-phenethyl-8-(bis(6'-hydroxy-3',4'-disulfide)hexylphosphono)furanyl)-adenine.

Anal. calcd for C₂₅H₃₂N₅O₆S₄P + 0.5 DMSO + 1.5 H₂O: C: 43.15; H: 5.29; N: 9.68.
Found: C: 43.38; H: 4.93; N: 9.34.

13.2: N⁹-phenethyl-8-((3',4'-disulfide)nonacyclicphosphono)furanyladenine.

Anal. calcd for C₂₁H₂₂N₅O₄S₂P + DMSO: C: 47.49; H: 4.85; N: 12.04. Found: C: 47.93; H: 4.60; N: 11.76.

Example 14.Preparation of substituted benzyl phosphonate diesters.

A suspension of 8-(2-(5-phosphono)furanyl)-N⁹-phenethyladenine (1 mmol) in thionyl chloride (5 mL) was warmed at refluxing 4 h. The cooled reaction mixture was evaporated to dryness and a solution of the resulting yellow residue was added to a solution of the corresponding benzyl alcohol (4 mmol), and pyridine (2.5 mmol) in methylene chloride. After stirring at 25 °C for 4 h the reaction mixture was subjected to extraction and chromatography to give the title compounds.

14.1: N⁹-phenethyl-8-(2-(5-(bis-(3-bromo-4-methoxy)benzyl)phosphono)-furanyl)adenine. Molecular mass calculated for C₃₃H₃₀N₅O₆Br₂P + H⁺: 784. Found:

25 784.

14.2: N⁹-phenethyl-8-(2-(5-(bis-(3-cyano-4-methoxy)benzyl)phosphono)-furanyl)adenine. Anal. calcd. for C₃₅H₃₀N₇O₆P + 0.5 H₂O : C: 61.40; H: 4.56; N: 14.32.
Found: C: 61.45; H: 4.51; N: 14.18.

14.3: N⁹-neopentyl-8-(2-(5-(bis-(4-acetoxy)benzyl)phosphono)furanyl)adenine. Anal. calcd. for C₃₂H₃₄N₅O₈P + 0.6 H₂O : C: 58.37; H: 5.39; N: 10.64. Found: C: 58.11; H: 5.28; N: 10.42.

5 N⁹-neopentyl-8-(2-(5-(bis-(3-phthalidyl-2-ethyl)phosphono)furanyl)-adenine is also prepared following the above described procedure using 2-(3-phthalidyl)ethanol which was prepared from phthalide-3-acetic acid in Example 27.

This reaction procedure can also be used to prepare diaryl ester prodrugs of phosphonates, such as substituted phenyl esters of phosphonate.

Example 15.

10 Preparation of 6-amino-8-(2-(5-diphenylphosphono)furanyl)-N⁹-(2-phenyl)ethylpurine.

Step A. A suspension of 6-chloro-8-(2-furanyl)-N⁹-phenethylpurine (1 mmol) in THF at -78 °C was treated with LDA (1.3 mmol) for 1 h. Then a solution of diphenyl chlorophosphate in THF was added and the reaction was stirred at -78 °C for another hour. The reaction was warmed to 0 °C and quenched with aqueous saturated sodium bicarbonate. Extraction and chromatography gave 6-chloro-8-(2-(5-diphenylphosphono)furanyl)-N⁹-phenethylpurine as a white solid. mp 117-118 °C .

Step B. A solution of 6-chloro-8-(2-(5-diphenylphosphono)furanyl)-N⁹-phenethylpurine (1 mmol) in DMF was treated with sodium azide (4 mmol) and triphenylphosphine (4 mmol) at room temperature for 3 h. Filtration, evaporation of the 20 filtrate followed by chromatography gave 6-triphenyl-phosphonoimino-8-(2-(5-diphenylphosphono)furanyl)-N⁹-(2-phenyl)ethylpurine as a beige foam.

Step C. A solution of 6-triphenylphosphonoimino-8-(2-(5-diphenylphosphono)furanyl)-9-(2-phenyl)ethylpurine (1 mmol) in THF was treated with aqueous hydrogen chloride at room temperature for 24 h. Evaporation and chromatography gave 25 6-amino-8-(2-(5-diphenylphosphono)furanyl)-N⁹-(2-phenyl)ethylpurine (**15.1**) as a pale yellow solid. mp 196-197 °C ; Anal. calcd. for C₂₉H₂₄N₅O₄P: C: 64.80; H: 4.50; N: 13.03; P: 5.76. Found: C: 64.50; H: 4.47; N: 12.98; P: 5.46.

Example 16.Preparation of acyloxymethylphosphonate diesters.

A solution of 8-(2-(5-phosphono)furanyl)-N⁹-phenethyladenine (1 mmol) in acetonitrile and N,N,N-diisopropylethylamine (5 mmol) was treated with

5 acyloxymethyl iodide (4 mmol) at 0 °C for 24 h. Extraction and chromatography gave the title compounds.

The following compounds were prepared according to this procedure:

16.1: 6-Amino-9-phenethyl-8-(2-(5-diisobutyrylmethylphosphono)furanyl)-purine.

Anal. calcd for C₂₇H₃₂N₅O₈P: C: 55.40; H: 5.50; N: 12.00. Found: C: 55.60; H: 5.60; N:

10 11.80.

16.2: 6-Amino-9-(2-cyclohexylethyl)-8-(2-(5-diisobutyrylmethylphosphono)-furanyl)purine. Anal. calcd for C₂₇H₃₈N₅O₈P + 0.7 H₂O: C: 53.70; H: 6.60; N: 11.60. Found: C: 54.00; H: 6.50; N: 11.20.

16.3: 6-Amino-9-ethyl-8-(2-(5-diisobutyrylmethylphosphono)-furanyl)purine.

15 Anal. calcd for C₂₁H₂₈N₅O₈P: C: 49.51; H: 5.54; N: 13.75. Found: C: 49.75; H: 5.37; N: 13.76.

16.4: 6-Amino-9-neopentyl-8-(2-(5-diisobutyrylmethylphosphono)furanyl)-purine.

Anal. calcd for C₂₄H₃₄N₅O₈P: C: 52.27; H: 6.21; N: 12.70. Found: C: 52.40; H: 6.27; N: 12.41.

20 **16.5:** 6-Amino-9-neopentyl-8-(2-(5-dipivaloxymethylphosphono)furanyl)purine.

Anal. calcd for C₂₆H₃₈N₅O₈P + 0.2 EtOAc: C: 53.90; H: 6.68; N: 11.73. Found: C: 54.10; H: 6.80; N: 11.42.

6-Amino-9-phenethyl-8-(2-(5-bis-(3-(5,6,7-trimethoxy)phthalidyl)-phosphono)furanyl)purine (**16.6**) was also synthesized following this procedure using 3-bromo-5,6,7-trimethoxyphthalide as the alkylating reagent to give the titled compound as a white solid after preparative HPLC purification. mp 155-160 °C ; Anal. calcd. for C₃₉H₃₆N₅O₁₄P + H₂O: C: 55.26; H: 4.52; N: 8.26. Found: C: 54.89; H: 4.75; N: 8.21.

Example 17.Preparation of 5-methyl-4-hydroxymethyl-2-oxo-1,3-dioxolene.

A solution of 4,5-dimethyl-2-oxo-1,3-dioxolene (1 mmol) and selenium dioxide (2.5 mmol) in dioxane was heated at reflux for 1 h. Evaporation, extraction and chromatography gave 5-methyl-4-hydroxymethyl-2-oxo-1,3-dioxolene as a yellow oil.
5 TLC: $R_f = 0.5$, 5 % MeOH-dichloromethane.

Example 18.Preparation of (5-substituted 2-oxo-1,3-dioxolen-4-yl)methyl phosphonate prodrugs.

A solution of N^9 -neopentyl-8-(2-(5-phosphono)furanyl)adenine (1 mmol) in
10 DMF and 2 mmol of sodium hydride is treated with 5-methyl-4-bromomethyl-2-oxo-1,3-dioxolene (4 mmol, prepared according to *Chem. Pharm. Bull.* **1984**, 32(6), 2241) at 25 °C for 24 h. Extraction and chromatography gives N^9 -neopentyl-8-(2-(5-bis(5-methyl-2-oxo-1,3-dioxolen-4-yl)methyl phosphono)-furanyl)adenine.

Alternatively, N^9 -neopentyl-8-(2-(5-bis(5-methyl-2-oxo-1,3-dioxolen-4-yl)methyl phosphono)-furanyl)adenine is prepared from N^9 -neopentyl-8-(2-(5-phosphono)furanyl)adenine and 5-methyl-4-hydroxymethyl-2-oxo-1,3-dioxolene (prepared from 4,5-dimethyl-2-oxo-1,3-dioxolene as described in Example 17) according to procedures of Example 14.

Example 19.20 Preparation of 2-(6-amino- N^9 -neopentylpurin-8-yl)phenyl phosphonate:

Step A. Triethylamine (1.1 mmol) was added slowly to an ice-cooled solution of 6-chloro- N^9 -neopentyl-8-(2-hydroxyphenyl)purine (1 mmol) and diethyl phosphite (1 mmol) in carbontetrachloride. The reaction was stirred at room temperature overnight. Triethylamine hydrochloride was precipitated as a white solid mass. Extraction and chromatography gave diethyl 2-(6-Chloro- N^9 -neopentylpurin-8-yl)phenyl phosphate.

Step B. Diethyl 2-(6-Chloro- N^9 -neopentylpurin-8-yl)phenyl phosphate was subjected to Step E and F in Example 2 to give the title compound (**19.1**). mp > 250 °C;

Anal. calcd. for $C_{16}H_{20}N_5O_4P + 1.25 H_2O$: C: 48.06; H: 5.67; N: 17.51. Found:
C: 48.42; H: 5.42; N: 17.15.

Example 20.

Preparation of N^9 -neopentyl-8-(1-(2-phosphono)imidazolemethyl)adenine:

5 Step A. A solution of 1-benzylimidazole (1.1 mmol) in THF was treated with LDA (1.1 mmol) at -78 °C for 1 h, and followed by addition of diethyl chlorophosphate (2 mmol), and stirred for 2 h. Extraction and chromatography gave 1-benzyl-2-diethylphosphonoimidazole as a yellow oil. TLC: $R_f = 0.35$, 80 % EtOAc-hexane.

10 Step B. A solution of 1-benzyl-2-diethylphosphonoimidazole (1 mmol) in EtOH was treated with palladium on carbon (10 %) at 25 °C under 1 atmosphere of hydrogen for 19 h. Filtration and evaporation gave 2-diethyl-phosphonoimidazole as a white solid. TLC: $R_f = 0.05$, 80 % EtOAc-hexane.

15 Step C. A solution of 8-bromomethyl-6-chloro- N^9 -neopentylpurine (1 mmol, Step H of Example 5), 2-diethylphosphonoimidazole (2.5 mmol), and N,N,N-diisopropylethylamine (2.5 mmol) in acetonitrile was stirred at 25 °C for 48 h. Extraction and chromatography gave 6-chloro- N^9 -neopentyl-8-(1-(2-diethylphosphono)imidazolemethyl)purine.

20 Step D. 6-Chloro- N^9 -neopentyl-8-(1-(2-diethylphosphono)imidazolemethyl)purine was subjected to Steps E and F in Example 2 to give the title compound (**20.1**). mp > 250 °C ; MS (M + H) calcd. for $C_{14}H_{20}N_7O_3P$: 366; found: 366.

Example 21.

Preparation of N^9 -phenethyl-8-(phosphonomethylaminocarbonyl)adenine:

25 Step A. N^9 -phenethyl-8-(methoxycarbonyl)adenine (1 mmol, prepared as in Step A of Example 5) was treated with sodium hydroxide (1.2 mmol) in THF:MeOH:H₂O (3:2:1) at 25 °C for 1.5 h. The reaction mixture was evaporated to dryness, and the residue was dissolved in DMF, treated with diethyl aminomethylphosphonate (1.5 mmol), EDCI (1-(3-dimethyl-aminopropyl)-3-ethylcarbodiimide hydrochloride, 1.3

mmol), HOBr (1-hydroxy-benzotriazole hydrate, 1.5 mmol), and stirred at 25 °C for 24 h. Extraction and chromatography gave N⁹-phenethyl-8-(diethylphosphonomethylaminocarbonyl)adenine as a white solid. TLC: R_f = 0.1, EtOAc.

Step B. N⁹-phenethyl-8-(diethylphosphonomethylaminocarbonyl)adenine (1

5 mmol) was subjected to Step F in Example 2 to give the title compound (**21.1**). mp > 250 °C; Anal. calcd. for C₁₅H₁₇N₆O₄P + 0.17 Toluene: C: 47.32; H: 4.50; N: 20.45. Found: C: 47.67; H: 4.57; N: 20.78.

Example 22.

Preparation of 2-substituted N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine:

10 Step A. A solution of 2-amino-4,6-dichloropyrimidine (1 mmol), neopentylamine (1.05 mmol), and triethylamine (2 mmol) in n-butanol was stirred at 110 °C for 12 h. Extraction and chromatography gave 2-amino-4-chloro-6-neopentylpyrimidine as a yellow solid. TLC: R_f = 0.2, 30 % EtOAc-hexane.

Step B. A mixture of 2-amino-4-chloro-6-neopentylpyrimidine (1 mmol),

15 sodium acetate (14 mmol), acetic acid (86 mmol), and 4-chlorobenzene-diazonium hexafluorophosphate (1.15 mmol) in water was stirred at 25 °C for 12 h. Extraction and evaporation gave a yellow solid which was treated with zinc dust (10 mmol) and acetic acid (5.54 mmol) in EtOH-H₂O at 80 °C for 1 h. Extraction and chromatography gave 4-chloro-2,5-diamino-6-neopentyl-pyrimidine as a yellow solid. TLC: R_f = 0.25, 50 %

20 EtOAc-hexane.

Step C. 4-Chloro-2,5-diamino-6-neopentylpyrimidine was subjected to Step D, E, F in Example 2 to give 2,6-diamino-N⁹-neopentyl-8-(2-(5-phosphono)furanyl)purine (**22.1**) as a yellow solid. mp 240 °C (decomp); Anal. calcd. for C₁₄H₁₉N₆O₄P + 2.2 HBr + 0.5 acetone: C: 32.47; H: 4.25; N: 14.66. Found: C: 32.31; H: 4.51; N: 14.85.

25 Similarly, 2-methylthio-N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine (**22.2**) was also prepared from 4-amino-6-chloro-2-methylthiopyrimidine as a yellow solid. mp > 250; Anal. calcd. for C₁₅H₂₀N₅O₄PS + 0.2 CH₂Cl₂ + 0.1 toluene: C: 45.08; H: 5.04; N: 16.53. Found: C: 45.27; H: 5.34; N: 16.24.

Example 23.Preparation of alkyloxycarbonyloxyalkyl phosphonate esters.

A solution of N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine (1 mmol) in 5 mL of anhydrous DMF is treated with *N,N'*-dicyclohexyl-4-morpholinecarboxamidine (5

5 mmol), and isopropylloxycarbonyloxymethyl iodide (5 mmol) which is prepared from the commercially available chloromethyl chloroformate according to the reported procedure, Nishimura et al. *J. Antibiotics*, 1987, 40(1), 81-90. The reaction mixture is stirred for 24 h at room temperature and the solvent is removed under reduced pressure. The resulting syrup is chromatographed on silica with 50% /50% EtOAc/Hexane to

10 yield N⁹-neopentyl-8-(2-(5-diisopropylloxycarbonyloxymethyl phosphono)furanyl)adenine.

Other alkyloxycarbonyloxymethyl, aryloxycarbonyloxymethyl , alkyl- and arylthiocarbonyloxymethyl phosphonate esters can also be prepared following the above described procedure.

15 Example 24.

Preparation of 1-substituted-1,3-propanediol cyclic esters of purine phosphonates.

Step A. (*J. Org. Chem.*, 1957, 22, 589)

To a solution of 2-pyridine propanol (72.9 mmol) in acetic acid (75 mL) was added 30% hydrogen peroxide slowly. The reaction mixture was heated to 80 °C for 16 h. The reaction was concentrated under vacuum and the residue was dissolved in acetic anhydride (100 mL) and heated at 110 °C overnight. Acetic anhydride was evaporated upon completion of reaction. Chromatography of the mixture by eluting with methanol-methylene chloride (1:9) resulted in 10.5 g of pure 2-(1-(1,3-diacetoxy)propyl)pyridine.

Step B. To a solution of 2-(1-(1,3-diacetoxy)propyl)pyridine (21.1 mmol) in

25 methanol-water (3:1, 40 mL) was added potassium carbonate (105.5 mmol). After stirring for 3 h at room temperature, the reaction mixture was concentrated. The residue was chromatographed by eluting with methanol-methylene chloride (1:9) to give 2.2 g of crystalline 2-(1-(1,3-dihydroxy)propyl)pyridine.

Step C. A suspension of N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine (1 mmol) in 5 mL of thionyl chloride was heated at reflux temperature for 4 h. The reaction mixture was cooled and evaporated to dryness. To the resulting residue was added a solution of 2-(1-(1,3-dihydroxy)propyl)pyridine (1 mmol) and pyridine (2.5 mmol) in 3 mL of methylene chloride. After stirring at 25 °C for 4 h the reaction was subjected to work up and chromatography to give N⁹-neopentyl-8-(2-(5-(1-(2-pyridyl)propan-1,3-yl)phosphono)furanyl)adenine (**24.1**) as a sticky solid. Anal. Calcd. for C₂₂H₂₅N₆O₄P + 0.75 H₂O + 1.0 HCl: C:50.97; H: 5.35; N: 16.21. Found: C:51.19, H: 5.02; N: 15.91.

Following the above described procedures, other cyclic esters are also prepared, such as N⁹-neopentyl-8-(2-(5-(1-(4-pyridyl)propan-1,3-yl)phosphono)furanyl)adenine, N⁹-neopentyl-8-(2-(5-(1-(3-pyridyl)propan-1,3-yl)phosphono)furanyl)adenine, and N⁹-neopentyl-8-(2-(5-(1-phenylpropan-1,3-yl)phosphono)furanyl)adenine.

Example 25.

15 Preparation of 2-substituted-1,3-propanediol cyclic esters of purine phosphonates.

Step A. To a solution of 2-(hydroxymethyl)-1,3-propanediol (1 g, 9.4 mmol) in pyridine (7.5 mL) at 0 °C was added acetic anhydride (0.89 mL, 9.4 mmol) slowly. The resulting solution was warmed to room temperature and stirred for 16 h. The reaction was concentrated under reduced pressure and chromatographed by eluting with methanol-dichloromethane (1:9) to give 510 mg of pure 2-acetoxymethyl-1,3-propanediol.

Step B. 2-Acetoxymethyl-1,3-propanediol was coupled to N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine following Step C of Example 24 to give N⁹-neopentyl-8-(2-(5-(2-(acetoxymethyl)propan-1,3-yl)phosphono)furanyl)adenine (**25.1**). mp = 164 - 165 °C; Anal. Calcd. for C₂₀H₂₆N₅O₆P: C: 51.84; H: 5.65; N: 15.11 . Found: C: 52.12; H: 5.77 ; N: 14.59.

Following the above described procedures, other cyclic esters are also prepared, such as N⁹-neopentyl-8-(2-(5-(2-(methoxycarbonyloxymethyl)-propan-1,3 -

yl)phosphono)furanyl)adenine, N⁹-neopentyl-8-(2-(5-(2-(hydroxymethyl)-propan-1,3 -yl)phosphono)furanyl)adenine, N⁹-neopentyl-8-(2-(5-(2,2-dihydroxymethylpropan-1,3 -yl)phosphono)furanyl)adenine. N⁹-neopentyl-8-(2-(5-(2-(methoxycarbonyloxymethyl)propan-1,3 -yl)phosphono)-furanyl)adenine is prepared by coupling N⁹-neopentyl-8-(2-(5-phosphono)-furanyl)adenine with 2-(methoxycarbonyloxymethyl)-1,3-propanediol which was prepared as follows:

To a solution of 2-(hydroxymethyl)-1,3-propanediol (9.4 mmol) in dichloromethane (20 mL) and pyridine (7.5 mL) at 0 °C was added methyl chloroformate (9.4 mmol) slowly. The resulting solution was warmed to room temperature and stirred for 16 h. The reaction was concentrated under reduced pressure and chromatographed by eluting with methanol-dichloromethane (1:4) to give 650 mg of 2-(methoxycarbonyloxymethyl)-1,3-propanediol.

Example 26.

Preparation of 8-(2-(5-hydroxyl-1,3 cyclohexyl)phosphono)furanylpurines.

A suspension of N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine (1 mmol) in 5 mL of thionyl chloride was heated at reflux temperature for 4 h. The reaction mixture was cooled and evaporated to dryness. To the resulting residue was added a solution of cis,cis-1,3,5-cyclohexanetriol (1 mmol) and pyridine (2.5 mmol) in 3 mL of methylene chloride. After stirring at 25 °C for 24 h the reaction was subjected to work up and chromatography to give N⁹-neopentyl-8-(2-(5-(5-hydroxyl-1,3 cyclohexyl)phosphono)furanyl)adenine, minor isomer (**26.1**). mp 248 - 250 °C; Anal. Cald. for C₂₀H₂₆N₅O₅P + 0.5 H₂O: C: 52.63; H: 5.96; N: 15.34. Found: C: 52.62; H: 5.70; N: 15.32; major isomer (**26.2**). mp 225 - 230°C; Anal. Cald. for C₂₀H₂₆N₅O₅P + 0.5 H₂O: C: 52.63; H: 5.96; N: 15.34. Found: C: 52.74 ; H: 5.80; N: 15.32.

Following the above described procedures, N⁹-phenethyl-8-(2-(5-(5-hydroxyl-1,3 cyclohexyl)phosphono)furanyl)adenine (**26.3**) was also prepared. Anal. Cald. for C₂₃H₂₄N₅O₅P + 0.15 H₂O: C: 57.06 ; H: 5.06 ; N: 14.47. Found: C: 56.84; H: 4.83; N: 14.38.

Example 27.Preparation of 3-(2-hydroxyethyl)phthalide.

A solution of phthalide-3-acetic acid (1 mmol) in THF was treated with borane dimethylsulfide (1.5 mmol) at 0 °C for 1h, and 25 °C for 24 h. Extraction and chromatography gave 2-(3-phthalidyl)ethanol as a light yellow oil. TLC: $R_f = 0.25$, 50 % EtOAc - hexane.

Example 28.Preparation of purine phosphonate amine salts

A mixture of N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine (1 mmol) and tris(hydroxymethyl)aminomethane (1.05 mmol) in methanol is stirred at 25 °C for 24 h. Evaporation give N⁹-neopentyl-8-(2-(5-phosphono)furanyl)adenine tris(hydroxymethyl)aminomethane salt .

Examples of the methods of the present invention includes the following. It will be understood that these examples are exemplary and that the method of the invention is not limited solely to these examples.

For the purposes of clarity and brevity, chemical compounds in the following biological examples are referred to by synthetic example numbers.

Besides the following Examples, assays that may be useful for identifying compounds which inhibit gluconeogenesis include the following animal models of

Diabetes:

i. Animals with pancreatic b-cells destroyed by specific chemical cytotoxins such as Alloxan or Streptozotocin (e.g. the Streptozotocin-treated mouse, -rat, -dog, and -monkey). Kodama, H., Fujita, M., Yamaguchi, I., *Japanese Journal of Pharmacology* 1994, 66, 331-336 (mouse); Youn, J.H., Kim, J.K., Buchanan, T.A., *Diabetes* 1994, 43, 564-571 (rat); Le Marchand, Y., Loten, E.G., Assimacopoulos-Jannet, F., et al.,

Diabetes 1978, 27, 1182-88 (dog); and Pitkin, R.M., Reynolds, W.A., *Diabetes* 1970, 19, 70-85 (monkey).

ii. Mutant mice such as the C57BL/Ks db/db, C57BL/Ks ob/ob, and C57BL/6J ob/ob strains from Jackson Laboratory, Bar Harbor, and others such as Yellow Obese,

5 T-KK, and New Zealand Obese. Coleman, D.L., Hummel, K.P., *Diabetologia* 1967, 3, 238-248 (C57BL/Ks db/db); Coleman, D.L., *Diabetologia* 1978, 14, 141-148 (C57BL/6J ob/ob); Wolff, G.L., Pitot, H.C., *Genetics* 1973, 73, 109-123 (Yellow Obese); Dulin, W.E., Wyse, B.M., *Diabetologia* 1970, 6, 317-323 (T-KK); and Bielschowsky, M., Bielschowsky, F. *Proceedings of the University of Otago Medical*

10 *School* 1953, 31, 29-31 (New Zealand Obese).

iii. Mutant rats such as the Zucker fa/fa Rat rendered diabetic with Streptozotocin or Dexamethasone, the Zucker Diabetic Fatty Rat, and the Wistar Kyoto Fatty Rat. Stolz, K.J., Martin, R.J. *Journal of Nutrition* 1982, 112, 997-1002 (Streptozotocin); Ogawa, A., Johnson, J.H., Ohnbeda, M., McAllister, C.T., Inman, L.,

15 Alam, T., Unger, R.H., *The Journal of Clinical Investigation* 1992, 90, 497-504 (Dexamethasone); Clark, J.B., Palmer, C.J., Shaw, W.N., *Proceedings of the Society for Experimental Biology and Medicine* 1983, 173, 68-75 (Zucker Diabetic Fatty Rat); and Idida, H., Shino, A., Matsuo, T., et al., *Diabetes* 1981, 30, 1045-1050 (Wistar Kyoto Fatty Rat).

20 iv. Animals with spontaneous diabetes such as the Chinese Hamster, the Guinea Pig, the New Zealand White Rabbit, and non-human primates such as the Rhesus monkey and Squirrel monkey. Gerritsen, G.C., Connell, M.A., Blanks, M.C., *Proceedings of the Nutrition Society* 1981, 40, 237 245 (Chinese Hamster); Lang, C.M., Munger, B.L., *Diabetes* 1976, 25, 434-443 (Guinea Pig); Conaway, H.H., Brown, C.J.,

25 Sanders, L.L. et al., *Journal of Heredity* 1980, 71, 179-186 (New Zealand White Rabbit); Hansen, B.C., Bodkin, M.L., *Diabetologia* 1986, 29, 713-719 (Rhesus monkey); and Davidson, I.W., Lang, C.M., Blackwell, W.L., *Diabetes* 1967, 16, 395-401 (Squirrel monkey).

v. Animals with nutritionally induced diabetes such as the Sand Rat, the Spiny Mouse, the Mongolian Gerbil, and the Cohen Sucrose-Induced Diabetic Rat. Schmidt-Nielsen, K., Hainess, H.B., Hackel, D.B., *Science* **1964**, *143*, 689-690 (Sand Rat); Gonet, A.E., Stauffacher, W., Pictet, R., et al., *Diabetologia* **1965**, *1*, 162-171 (Spiny Mouse); Boquist, L., *Diabetologia* **1972**, *8*, 274-282 (Mongolian Gerbil); and Cohen, A.M., Teitelbaum, A., Saliternik, R., *Metabolism* **1972**, *21*, 235-240 (Cohen Sucrose-Induced Diabetic Rat).

5 vi. Any other animal with one of the following or a combination of the following characteristics resulting from a genetic predisposition, genetic engineering, selective breeding, or chemical or nutritional induction: impaired glucose tolerance, insulin resistance, hyperglycemia, obesity, accelerated gluconeogenesis, increased hepatic glucose output.

10

Example A: Inhibition of Human Liver FBPase

E. coli strain BL21 transformed with a human liver FBPase-encoding plasmid was obtained from Dr. M. R. El-Maghrabi at the State University of New York at Stony Brook. hFBPase was typically purified from 10 liters of *E. coli* culture as described (M. Gidh-Jain et al., *The Journal of Biological Chemistry* **1994**, *269*, 27732-27738). Enzymatic activity was measured spectrophotometrically in reactions that coupled the formation of product (fructose 6-phosphate) to the reduction of dimethylthiazoldiphenyltetrazolium bromide (MTT) via NADP and phenazine methosulfate (PMS), using phosphoglucose isomerase and glucose 6-phosphate dehydrogenase as the coupling enzymes. Reaction mixtures (200 µL) were made up in 96-well microtitre plates, and consisted of 50 mM Tris-HCl, pH 7.4, 100 mM KCl, 5 mM EGTA, 2 mM MgCl₂, 0.2 mM NADP, 1 mg/mL BSA, 1 mM MTT, 0.6 mM PMS, 1 unit/mL phosphoglucose isomerase, 2 units/mL glucose 6-phosphate dehydrogenase, and 0.150 mM substrate (fructose 1,6-bisphosphate). Inhibitor concentrations were varied from 0.01 µM to 10 µM. Reactions were started by the addition of 0.002 units of

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20

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pure hlFBPase and were monitored for 7 minutes at 590 nm in a Molecular Devices Plate Reader (37 °C).

The following Table depicts the IC₅₀ values for several compounds prepared in the Examples. AMP has an IC₅₀ value of 1.0 μM in this assay.

5

Example

| Compound Number | IC ₅₀ (human liver FBPase) | μM |
|-----------------|---------------------------------------|----|
| 2.1 | 5 | μM |
| 2.2 | 1.4 | μM |
| 2.3 | 3.3 | μM |
| 2.7 | 0.8 | μM |
| 2.10 | 2 | μM |
| 2.13 | 4.5 | μM |
| 2.14 | 0.9 | μM |
| 2.16 | 1.4 | μM |
| 4.1 | 100 | μM |
| 5.5 | 10 | μM |
| 8.1 | 23 | μM |
| 10.1 | 50 | μM |
| 11.1 | 0.7 | μM |
| 12.1 | 13 | μM |

Figure 2 shows the dose-dependent inhibition of hlFBPase by AMP, compound **2.7**, compound **2.13**, and compound **2.5**.

10 ***In vitro* inhibition of rat liver and mouse liver FBPase was also determined.**

E. coli strain BL21 transformed with a rat liver FBPase-encoding plasmid was obtained from Dr. M. R. El-Maghrabi at the State University of New York at Stony Brook, and purified as described (El-Maghrabi, M.R., and Pilkis, S.J. *Biochem.*

Biophys. Res. Commun. 1991, 176, 137-144). Mouse liver FBPase was obtained by

5 homogenizing freshly isolated mouse liver in 100 mM Tris-HCl buffer, pH 7.4, containing 1 mM EGTA, and 10 % glycerol. The homogenate was clarified by centrifugation, and the 45-75 % ammonium sulfate fraction prepared. This fraction was redissolved in the homogenization buffer and desalted on a PD-10 gel filtration column (Biorad) eluted with same. This partially purified fraction was used for enzyme assays.

10 Both rat liver and mouse liver FBPase were assayed as described for human liver FBPase. Generally, as reflected by the higher IC₅₀ values, the rat and mouse liver enzymes are less sensitive to inhibition by the compounds tested than the human liver enzyme.

15 The following Table depicts the IC₅₀ values for several compounds prepared in the Examples:

| Compound | IC ₅₀ Rat Liver | IC ₅₀ Mouse Liver |
|-------------|----------------------------|------------------------------|
| | μM | μM |
| 2.1 | 100 | >20 |
| 2.2 | >20 | >20 |
| 2.3 | >20 | >20 |
| 2.7 | 1.25 | 55 |
| 2.10 | >20 | >20 |
| 2.13 | >20 | >20 |
| 2.14 | >20 | >20 |
| 2.16 | >20 | >20 |
| 4.1 | >20 | >20 |
| 5.5 | >20 | >20 |
| 8.1 | >20 | >20 |

| | | |
|------|-----|------|
| 10.1 | >20 | >20 |
| 11.1 | >20 | >20 |
| 12.1 | 20 | >100 |

Example B: AMP Site Binding

To determine whether compounds bind to the allosteric AMP binding site of hFBPase, the enzyme was incubated with radiolabeled AMP in the presence of a range of test compound concentrations. The reaction mixtures consisted of 25 mM ^3H -AMP

5 (54 mCi/mmol) and 0 -1000 nM test compound in 25 mM Tris-HCl, pH 7.4, 100 mM KCl and 1 mM MgCl₂. 1.45 mg of homogeneous FBPase (\pm 1 nmole) was added last.

After a 1 minute incubation, AMP bound to FBPase was separated from unbound AMP by means of a centrifugal ultrafiltration unit ("Ultrafree-MC", Millipore) used according to the instructions of the manufacturer. The radioactivity in aliquots (100 μ l)

10 of the upper compartment of the unit (the retentate, which contains enzyme and label) and the lower compartment (the filtrate, which contains unbound label) were quantified using a Beckman liquid scintillation counter. The amount of AMP bound to the enzyme was estimated by comparing the counts in the filtrate (the unbound label) to the total counts in the retentate.

15 As evident from Fig. 3, both aminoimidazolecarboxamideriboside monophosphate (ZMP) and compound 2.2 displaced AMP from hFBPase in a dose-dependent manner, indicating that they bind to the same site on the enzyme as AMP. As expected, compound 2.2, a more potent hFBPase inhibitor than ZMP (IC_{50} 's = 5 and 12 μ M, respectively), had a lower ED_{50} for AMP displacement than ZMP (35 vs 20 250 μ M).

Example C: AMP Site/Enzyme Selectivity

To determine the selectivity of compounds towards FBPase, effects of FBPase inhibitors on 5 key AMP binding enzymes were measured using the assays described below:

Adenosine Kinase: Human adenosine kinase was purified from an *E. coli* expression system as described by Spychala et al. (Spychala, J., Datta, N.S., Takabayashi, K., Datta, M., Fox, I.H., Gribbin, T., and Mitchell, B.S. *Proc. Natl. Acad. Sci. USA* **1996**, *93*, 1232-1237). Activity was measured essentially as described by Yamada et al.

5 (Yamada, Y., Goto, H., Ogasawara, N. *Biochim. Biophys. Acta* **1988**, *660*, 36-43.) with a few minor modifications. Assay mixtures contained 50 mM TRIS-maleate buffer, pH 7.0, 0.1 % BSA, 1 mM ATP 1 mM MgCl₂, 1.0 µM [^{U-14}C] adenosine (400-600 mCi/mmol) and varying duplicate concentrations of inhibitor. ¹⁴C-AMP was separated from unreacted ¹⁴C-adenosine by absorption to anion exchange paper (Whatman) and 10 quantified by scintillation counting.

Adenosine Monophosphate Deaminase: Porcine heart AMPDA was purified essentially as described by Smiley et al. (Smiley, K.L., Jr, Berry, A.J., and Suelter, C.H. *J. Biol. Chem.* **1967**, *242*, 2502-2506) through the phosphocellulose step. Inhibition of AMPDA activity was determined at 37 °C in a 0.1 mL assay mixture containing

15 inhibitor, ~0.005U AMPDA, 0.1 % bovine serum albumin, 10 mM ATP, 250 mM KCl, and 50 mM MOPS at pH 6.5. The concentration of the substrate AMP was varied from 0.125 - 10.0 mM. Catalysis was initiated by the addition of enzyme to the otherwise complete reaction mixture, and terminated after 5 minutes by injection into an HPLC system. Activities were determined from the amount of IMP formed during 5 minutes.

20 IMP was separated from AMP by HPLC using a Beckman Ultrasil-SAX anion exchange column (4.6 mm x 25 cm) with an isocratic buffer system (12.5 mM potassium phosphate, 30 mM KCl, pH 3.5) and detected spectrophotometrically by absorbance at 254 nm.

Phosphofructokinase: Enzyme (rabbit liver) was purchased from Sigma. Activity was 25 measured at 30 °C in reactions in which the formation of fructose 1,6-bisphosphate was coupled to the oxidation of NADH via the action of aldolase, triosephosphate isomerase, and α-glycerophosphate dehydrogenase. Reaction mixtures (200 µl) were

made up in 96-well microtitre plates and were read at 340 nm in a Molecular Devices Microplate Reader. The mixtures consisted of 200 mM Tris-HCl pH 7.0, 2 mM DTT, 2 mM MgCl₂, 0.2 mM NADH, 0.2 mM ATP, 0.5 mM Fructose 6-phosphate, 1 unit aldolase/mL, 3 units/mL triosephosphate isomerase, and 4 units/mL

5 α-glycerophosphate dehydrogenase. Test compound concentrations ranged from 1 to 500 μM. Reactions were started by the addition of 0.0025 units of phosphofructokinase and were monitored for 15 minutes.

Glycogen Phosphorylase: Enzyme (rabbit muscle) was purchased from Sigma.

Activity was measured at 37 °C in reactions in which the formation of glucose 1-

10 phosphate was coupled to the reduction of NADP via phosphoglucomutase and glucose 6-phosphate dehydrogenase. Assays were performed on 96-well microtitre plates and were read at 340 nm on a Molecular Devices Microplate Reader. Reaction mixtures consisted of 20 mM imidazole, pH 7.4, 20 mM MgCl₂, 150 mM potassium acetate, 5 mM potassium phosphate, 1 mM DTT, 1 mg/mL BSA, 0.1 mM NADP, 1 unit/mL phosphoglucomutase, 1 unit/mL glucose 6-phosphate dehydrogenase, 0.5 % glycogen.

15 Test compound concentrations ranged from 1 to 500 μM. Reactions were started by the addition of 17 μg enzyme and were monitored for 20 minutes.

Adenylate Kinase: Enzyme (rabbit muscle) was purchased from Sigma. Activity was measured at 37 °C in reaction mixtures (100 μl) containing 100 mM Hepes, pH 7.4, 45

20 mM MgCl₂, 1 mM EGTA, 100 mM KCl, 2 mg/mL BSA, 1 mM AMP and 2 mM ATP. Reactions were started by addition of 4.4 ng enzyme and terminated after 5 minutes by addition of 17 μl perchloric acid. Precipitated protein was removed by centrifugation and the supernatant neutralized by addition of 33 μl 3 M KOH/3 M KH₂CO₃. The neutralized solution was clarified by centrifugation and filtration and analyzed for ADP content (enzyme activity) by HPLC using a YMC ODS AQ column (25 X 4.6 cm). A gradient was run from 0.1 M KH₂PO₄, pH 6, 8 mM tetrabutyl ammonium hydrogen sulfate to 75 % acetonitrile. Absorbance was monitored at 254 nM.

Compound **2.1**, a 5 μ M hFBPase inhibitor, was essentially inactive in all of the above described assays except for the AMP deaminase screen: half-maximal inhibition of AMP deaminase was observed at almost the same concentration as the IC₅₀ for FBPase. Compound **2.7** (hFBPase IC₅₀ = 0.8 μ M), in addition to being essentially without effect on adenosine kinase, adenylate kinase, glycogen phosphorylase, and phosphofructokinase, was only a weak inhibitor of AMP deaminase (IC₅₀ = 390 μ M). The data suggest that compound **2.7** binds to hFBPase in a highly selective manner. The following Table gives the selectivity data for compounds **2.1** and **2.7**.

| | <u>SELECTIVITY</u> | |
|-------------------------------|---------------------|---------------------|
| | <u>Compound 2.1</u> | <u>Compound 2.7</u> |
| FBPase (inh.) | 5.0 μ M | 0.8 μ M |
| Adenosine Kinase (inh.) | >>10 | >>100 |
| Adenylate Kinase (inh.) | >>500 | >>500 |
| AMP Deaminase (inh.) | 6.7 | 390 |
| Glycogen Phosphorylase (act.) | >>250 | >>100 |
| Phosphofructokinase (act.) | >>200 | >>100 |

10

Example D: Inhibition of Gluconeogenesis in Rat Hepatocytes

Hepatocytes were prepared from overnight fasted Sprague-Dawley rats (250-300 g) according to the procedure of Berry and Friend (Berry, M.N., Friend, D.S., *J. Cell. Biol.* **1969**, *43*, 506-520) as modified by Groen (Groen, A.K., Sips, H.J., Vervoorn,

15 R.C., Tager, J.M., *Eur. J. Biochem.* **1982**, *122*, 87-93). Hepatocytes (75 mg wet weight/mL) were incubated in 1 mL Krebs-bicarbonate buffer containing 10 mM Lactate, 1 mM pyruvate, 1 mg/mL BSA, and test compound concentrations from 1 to 500 μ M. Incubations were carried out in a 95 % oxygen, 5 % carbon dioxide atmosphere in closed, 50-mL Falcon tubes submerged in a rapidly shaking water bath 20 (37 °C). After 1 hour, an aliquot (0.25 mL) was removed, transferred to an Eppendorf

tube and centrifuged. 50 μ l of supernatant was then assayed for glucose content using a Sigma Glucose Oxidase kit as per the manufacturer's instructions.

Compound **2.1** and compound **2.7** inhibited glucose production from lactate/pyruvate in isolated rat hepatocytes in a dose-dependent manner, with IC₅₀'s of 5 90 and 4.5 μ M, respectively (Figure 5). IC₅₀'s for other select compounds in this assay are shown in the Table below:

| Compound | IC ₅₀ Glucose Production, μ M |
|-------------|--|
| 2.2 | 90 |
| 2.6 | 18 |
| 2.10 | 24 |
| 2.13 | 50 |
| 2.14 | 7.5 |
| 2.16 | 12 |
| 16.4 | 3 |

FPBase from rat liver is less sensitive to AMP than that from human liver. IC₅₀ values are correspondingly higher in rat hepatocytes than would be expected in human hepatocytes.

10 **Example E: Effect of Compound 2.7 on gluconeogenesis from Dihydroxyacetone in Rat Hepatocytes: Glucose Production Inhibition and Fructose 1,6-bisphosphate Accumulation**

Isolated rat hepatocytes were prepared as described in Example D and incubated under the identical conditions described except that lactate/pyruvate was replaced by 15 10 mM dihydroxyacetone, a substrate which feeds into the gluconeogenic pathway at a step just prior to FBPase. Reactions were terminated by removing an aliquot (250 μ L) of cell suspension and spinning it through a layer of oil (0.8 mL silicone/mineral oil, 4/1) into a 10 % perchloric acid layer (100 μ L). After removal of the oil layer, the

acidic cell extract layer was neutralized by addition of 1/3rd volume of 3 M KOH/3 M KH₂CO₃. After thorough mixing and centrifugation, the supernatant was analyzed for glucose content as described in Example D, and also for fructose-1,6-bisphosphate.

Fructose-1,6-bisphosphate was assayed spectrophotometrically by coupling its

5 enzymatic conversion to glycerol 3-phosphate to the oxidation of NADH, which was monitored at 340 nm. Reaction mixtures (1 mL) consisted of 200 mM Tris-HCl, pH 7.4, 0.3 mM NADH, 2 units/mL glycerol 3-phosphate dehydrogenase, 2 units/mL triosephosphate isomerase, and 50-100 µl cell extract. After a 30 minute preincubation at 37 °C, 1 unit/mL of aldolase was added and the change in absorbance measured until 10 a stable value was obtained. 2 moles of NADH are oxidized in this reaction per mole of fructose-1,6-bisphosphate present in the cell extract.

As shown in Figure 4A, compound **2.7** inhibited glucose production from dihydroxyacetone in rat hepatocytes (IC₅₀ approx. 5 µM) as effectively as from lactate pyruvate (IC₅₀ 4.5 µM, Figure 5). This data confirms that the site of action of the 15 compound is in the last four steps of the gluconeogenic pathway. The dose-dependent accumulation of fructose-1,6-bisphosphate (the substrate of FBPase) that occurs upon cell exposure to compound **2.7** (Figure 4B) is consistent with the inhibition of FBPase, the second to last enzyme in the pathway.

Example F: Blood Glucose Lowering in Fasted Rats

20 Sprague Dawley rats (250-300 g) were fasted for 18 hours and then dosed intraperitoneally either with saline or with 35, 45, and 60 mg/kg compound **16.4**, a prodrug of compound **2.7**. The vehicle used for drug administration was dimethylsulfoxide. Blood samples were obtained from the tail vein of conscious animals just prior to injection and then at half-hourly intervals. Blood glucose was 25 measured using a HemoCue Inc. glucose analyzer according to the instructions of the manufacturer.

Figure 6 shows the profound glucose lowering elicited by treatment with compound **16.4**. The duration of action was dose-dependent and ranged from 2 to 6 hours.

Example G: Analysis of Drug Levels and Liver Fructose-1,6-bisphosphate

5 Accumulation In Rats

Sprague-Dawley rats (250-300 g) were fasted for 18 hours and then dosed intraperitoneally either with saline ($n = 3$) or 20 mgs/kg compound **2.7** ($n = 4$). The vehicle used for drug administration was 10 mM bicarbonate. One hour post injection rats were anesthetized with halothane and a liver biopsy (approx. 1 g) was taken as well as a blood sample (2 mL) from the posterior vena cava. A heparin flushed syringe and needle were used for blood collection. The liver sample was immediately homogenized in ice-cold 10% perchloric acid (3 mL), centrifuged, and the supernatant neutralized with 1/3rd volume of 3 M KOH/3 M KH₂CO₃. Following centrifugation and filtration, 50 μ L of the neutralized extract was analyzed for compound **2.7** content by HPLC. A reverse phase YMC ODS AQ column (250 X 4.6 cm) was used and eluted with a gradient from 10 mM sodium phosphate pH 5.5 to 75 % acetonitrile. Absorbance was monitored at 310 nm. The concentration of fructose-1,6-bisphosphate in liver was also quantified using the method described in Example E. Blood glucose was measured in the blood sample as described in Example F. Plasma was then quickly prepared by centrifugation and extracted by addition of methanol to 60 % (v/v). The methanolic extract was clarified by centrifugation and filtration and then analyzed by HPLC as described above.

Compound **2.7** lowered blood glucose from 82 ± 3 to 28 ± 9.9 mg/dL within one hour (Figure 7). Drug levels measured in plasma and liver were 38.5 ± 7 μ M and 51.3 ± 10 nmoles/ g, respectively. As shown in Figure 8, a 10-fold elevation of fructose-1,6-bisphosphate levels was found in the livers from the drug-treated group, consistent with the inhibition of glucose production at the level of FBPase in the gluconeogenic pathway.

Example H: Blood Glucose Lowering in Zucker Diabetic Fatty Rats

Zucker Diabetic Fatty rats purchased at 7 weeks of age were used at age 16 weeks in the 24-hour fasted state. The rats were purchased from Genetics Models Inc. and fed the recommended Purina 5008 diet (6.5 % fat). Their fasting hyperglycemia at 5 24 hours ranged from 150 mg/dL to 310 mg/dL blood glucose.

Compound 2.7 was administered at a dose of 50 mg/kg by intraperitoneal injection (n = 6). The stock solution was made up at 25 mg/mL in deionized water and adjusted to neutrality by dropwise addition of 5 N NaOH. 5 control animals were dosed with saline. Blood glucose was measured at the time of dosing and 2 hours post 10 dose as described in Example F.

As shown in Figures 9A and 9B, blood glucose was lowered in the drug-treated group by an average of almost 20 % (p < 0.0001 relative to the control animals).

Example I: Inhibition of Gluconeogenesis in Zucker Diabetic Fatty Rats

Three 20-week old Zucker Diabetic Fatty rats were dosed with compound 2.7 15 and three with saline as described in Example H. Fifteen minutes post-injection, the animals were anesthetized with sodium pentobarbital (30 mgs, i.p.) and ¹⁴C-bicarbonate (20 µCi /100 g of body weight) was administered via the tail vein. Blood samples (0.6 mL) were obtained by cardiac puncture 10 and 20 minutes post tracer injection. Blood (0.5 mL) was diluted into 6 mL deionized water and protein precipitated by addition of 20 1 mL zinc sulfate (0.3 N) and 1 mL barium hydroxide (0.3 N). The mixture was centrifuged (20 minutes, 1000X g) and 5 mL of the resulting supernatant was then combined with 1 g of a mixed bed ion exchange resin (1 part AG 50W-X8, 100-200 mesh, hydrogen form and 2 parts of AG 1-X8, 100-200 mesh, acetate form) to separate ¹⁴C-bicarbonate from ¹⁴C-glucose. The slurry was shaken at room temperature for four 25 hours and then allowed to settle. An aliquot of the supernatant (0.5 mL) was then counted in 5 mL scintillation cocktail.

As shown in Figure 10, compound **2.7** reduced the incorporation of ^{14}C -bicarbonate into glucose by 75 %; therefore gluconeogenesis was clearly inhibited by the drug.

Example J: Blood Glucose Lowering in Streptozotocin-treated Rats

5 Diabetes is induced in male Sprague-Dawley rats (250-300g) by intraperitoneal injection of 55 mg/kg streptozotocin (Sigma Chemical Co.). Six days later, 24 animals are selected with fed blood glucose values (8 am) between 350 and 600 mg/dL and divided into two statistically equivalent groups. Blood glucose is measured in blood obtained from a tail vein nick by means of a HemoCue Inc. (Mission Viejo, CA)

10 10 glucose analyzer. One group of 12 will subsequently receive inhibitor (100 mg/kg intraperitoneally) and the other 12 ("controls") an equivalent volume of saline. Food is removed from the animals. Blood glucose is measured in each animal four hours after dosing, and a second dose of drug or saline is then administered. Four hours later, a final blood glucose measurement is made.

15 **Example K: Evaluation of Compound 16.4 as a Prodrug in Rat Hepatocytes - Intracellular Delivery of Compound 2.7**

Rat hepatocytes were prepared and incubated as in Example D, except that the test compound, **16.4**, was added to yield a final concentration of 10 μM . Aliquots of the cell suspension were taken at 0, 5, 10, 20, 30, 45, and 60 minutes after drug exposure.

20 The cells were extracted and analyzed for compound **2.7** content by HPLC as described in Example L. Absorbance of the HPLC column eluate was monitored at 310 nm. Quantitation of intracellular compound **2.7** was done by comparison to authentic standards of known concentration. As shown in Figure 11A, compound **16.4** rapidly delivered high levels of compound **2.7** into the hepatocytes; a concentration of approximately 80 nmoles/g was achieved within 10 minutes. These data indicate that compound **16.4** readily penetrates cells and is efficiently de-esterified to the parent

compound, **2.7**, intracellularly. Furthermore, as shown in Figure 11B, compound **16.4** inhibited glucose production in rat hepatocytes.

Example L: Estimation of the oral bioavailability of prodrugs of phosphonic acids:

5 Prodrugs were dissolved in 10 % ethanol/90 % polyethylene glycol (mw 400) and administered by oral gavage at doses of approximately 20 or 40 mg/kg parent compound equivalents to 6-hour fasted, Sprague Dawley rats (220-240 g). The rats were subsequently placed in metabolic cages and urine was collected for 24 hours. The quantity of parent compound excreted into urine was determined by HPLC analysis. An 10 ODS column eluted with a gradient from potassium phosphate buffer, pH 5.5 to acetonitrile was employed for these measurements. Detection was at 310-325 nm. The percentage oral bioavailability was estimated by comparison of the recovery in urine of the parent compound generated from the prodrug, to that recovered in urine 24 hours after intravenous administration of unsubstituted parent compound at approximately 10 15 mg/kg. Parent compounds were typically dissolved in dimethyl sulfoxide, and administered via the tail vein in animals that were briefly anesthetized with halothane.

For compound **16.4**, a prodrug of compound **2.7**, 6.2 % of an oral dose of approximately 20 mg/kg was recovered in urine. For compound **2.7**, 76.8 % of an intravenous dose of approximately 10 mg/kg was recovered. The oral bioavailability of compound **16.4** was therefore calculated to be 6.2/76.8, or approximately 8 %. The oral bioavailability of compound **16.5** was also estimated following the above described protocol to be 5.3 %.

Example M. Glucose lowering following oral administration of FBPase inhibitors:

FBPase inhibitor was administered by oral gavage at doses of 30, 100 and 250 mg/kg to 25 18-hour fasted, Sprague Dawley rats (250-300g; n= 4-5/group). The compound was prepared in deionized water, adjusted to neutrality with sodium hydroxide, and brought

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into solution by sonication prior to administration. Blood glucose was measured immediately prior to dosing, and at 1 hour intervals thereafter. Blood samples were obtained from the tail vein, and measurements made by means of a Hemocue glucose analyzer (Hemocue Inc, Mission Viejo, California) used according to the manufacturer's instructions.

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